Carbon Monoxide Levels in Kitchens and Homes with Gas Cookers

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It always has been assumed that only a small amount of CO will be produced by a gas stove when mixture of air and gas are well adjusted and that that small amount will be dissipated by the home's ventilation and by a combination of a fan and hood over the stove. However, preparation of meals may substantially increase CO. The immediate air supply may be progressively diminished when more than one burner is used and air supply may be partially cut off by vessels placed over the gas flame. The purpose of this investigation was to determine the amount of CO that may be expected to be produced during normal cooking. The experiment measured CO levels, using multiple burners with and without cooking vessels, and the rate of dissipation of the accumulated gas under various conditions of ventilation.

Goldsmith[1] estimated that as many as 100,000 cases of some form of carbon monoxide poisoning may have occurred in U.S. homes and Amiro[2] found excess CO in large numbers of homes using gas for heating and cooking. A number of factors have now combined that draw attention to CO levels in homes where cooking is done with gas: (1) chronic exposure to carbon monoxide has been shown to result in serious health effects;[1,3–6] (2) substantially increased incidence of respiratory diseases among children has been reported in homes where gas stoves are used for cooking;[7] (3) tightly insulating homes in order to conserve fuel may, as a consequence, cut down ventilation. There are now reports of CO poisoning in tightly insulated homes.[8]

Methods

Nine kitchens with gas stoves were selected more or less at random from faculty, staff, and students at Simon Fraser University. None of the houses had been especially well insulated. One house was used to conduct a series of experiments determining the growth and dissipation of CO under various normal conditions of cooking and ventilation. Measurements of CO were obtained on a gas stove set for normal air supply. One to four burners were used with and without being capped by cooking vessels. CO measurements were obtained in the kitchen and adjacent dining and living areas. Dissipation of CO was tested when windows were closed, when the fan in the hood over the stove was in operation, when windows were open on one side of the house, and finally when windows were open on both sides allowing for cross ventilation. During the "cooking" period measurements were obtained every 2 minutes for a 30 min period. During the "ventilation" period measurements were first obtained every 2 min during the first 10 min after the gas stove had been turned off, and thereafter every 5 min for an additional 80 min. CO levels were measured during the cooking phase in the other 8 homes. Measurements were made with pans over the fire for a period of 30 min. Measurements were taken every 2 min. During the ventilation phase windows were kept closed and measurements obtained every 2 min for the first 10 min after the gas had been turned off and thereafter every 5 min for a period of 80 min.

Ambient levels of CO were obtained inside and outside the house at the beginning and end of each experiment.

Carbon monoxide was measured using an Ecolyzer 2000 gaseous sampler. In the Ecolyzer 2000, a gaseous sample is continuously drawn over an electrode where the CO is oxidized to CO_2 inducing an electrode potential. This potential, which is proportional to the concentration of CO_2 present in the sample, is displayed on a meter in parts per million (ppm). The sampler used in this experiment was calibrated with test gas of known concentration of 20 ppm CO. (The accuracy and reliability of the machine used by us was also determined by its use in other experiments.)

The Ecolyzer 2000 series instruments have been evaluated against NDIR instrumentation using split sample comparisons. These tests have found a high correlation ($r = 0.94$) between the Ecolyzer 2000 and NDIR results.[9] Also, according to the manufacturer's specifications and reports, the sampler has a reproducibility of ±1.0% of full scale and a mean drift of less than 1 ppm/24 hr. (Both claims were verified in our own use of this instrument.)

In order to avoid contaminating gas readings with fumes, particles, or steam produced by actual cooking, empty cast iron pans were used to cover the flames. All measurements were obtained at an elevation of 5 ft from the floor.

Results

Figure 1 shows the increase in CO when using 1 to 4 covered and uncovered burners. The rate of increase is sharply linear for the period of cooking and depends on the number of burners used. Placing a pan over the flame substantially increases the rate of CO production.

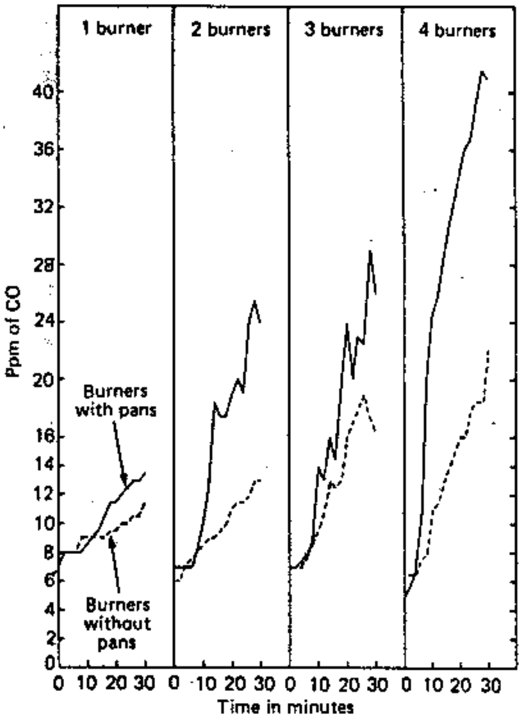

Figure 1. Increases in CO when using 1 to 4 covered and uncovered burners.

Carbon monoxide quickly diffuses throughout the house. Once spread it dissipates slowly depending on conditions of ventilation. Figure 2 shows CO levels in the kitchen, dining area (adjacent to the kitchen), and living area (adjacent to the dining area) for 90 min after the stove had been turned off. Figure 3 shows the disappearance of CO from the kitchen under various conditions of ventilation. (There is a rise in CO during the first few minutes after the stove has been turned off. CO first rises with the heated air and then diffuses back down as well as sideways as the air cools. Thus the rise of CO after the stove has been turned off is an artifact of the way the Ecolyzer was placed—in the position of the cook's face.)

Either using a hood and fan over the stove or open windows (but without providing cross ventilation) will result in moderate decrease in CO. Effective cross ventilation is required to reduce CO levels quickly. Buildup of CO in kitchens and adjacent rooms and dissipation rates were similar for the other 9 houses tested (not shown here).

Phase 2 of the experiment obtained CO readings in 9 different homes. Table I shows the initial values of CO at the onset of the experiment, CO readings in the kitchen after 20

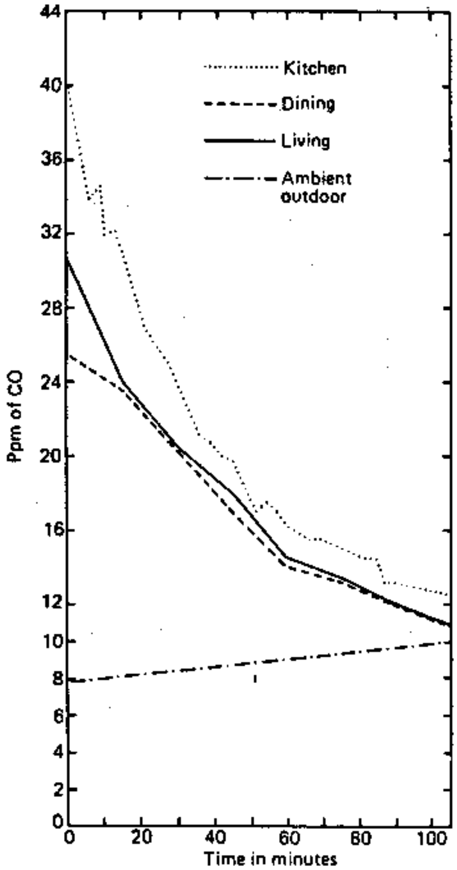

Figure 2. CO levels in the kitchen, dining area, and living area for 90 minutes after turning off the stove.

min of cooking, the rate of increase of CO, and the inside volume of the house through which the gas could diffuse.

The rate of increase is of special interest. If CO level is plotted against time (as in Figure 1) CO level increases as a linear function of time. This increase can be described by a simple equation $c = at$, when c is an increment of the value of CO in the increment of time t, (in minutes) and a, commonly called "rate of change" or "slope" describes the rate with which CO increases during the period of cooking. To give substantive meaning to a consider that a slope of 1 implies that 1 ppm of CO is added to the kitchen atmosphere each minute while for $a = 2$ or 3 respectively, 2 ppm or 3 ppm are added to the room's atmosphere during each minute. Actually, because of the rapid diffusion of CO through the house, $c = at$ describes the buildup of CO throughout that part of the house used most frequently during the daytime.

Table II shows that levels of CO in the dining and living area were approximately the same as in the kitchen. CO levels were steeply elevated even 90 minutes after cooking. (Outside ambient levels had not changed significantly from those shown in Table I.)

As all experiments were conducted in the morning hours, the initial CO values were due to the gas leaking in from outside traffic. (Inside and outside CO measurements were almost identical.)

One interesting observation concerns the relationship between the rate of increase of CO and the total volume of air in the house. As in most homes and apartments, the kitchen doors were kept open during cooking. It was thought that the rate of increase of CO in the kitchen might depend on the total volume of air in the house. Figure 4 shows a scattergram between total effective house volume (the volume of space contained in the kitchen and adjacent rooms) and rate of increase of CO. Clearly these two are related. The Pearson Moment Correlation Coefficient was computed between rate a and house volume. The value of $r = 0.7$ was statistically significant for number of observations with $p < 0.02$. This relationship also demonstrates the extreme rapidity with which CO diffuses through all the rooms in the house so that the rate of increase of CO during cooking depends not only on the number of burners used but also on the total effective volume of air into which CO can diffuse.

Table I. Initial and 20 minutes CO values, rates of increase and house volume for nine different kitchens.

House	Initial CO level (ppm)	CO level after 20 minutes (ppm)	Rate of CO increase[a]	Inside volume of house (ft^3)
1	5.0	34.5	1.3	4696
2	7.5	55.0	2.2	4000
3	4.0	80.0	2.9	1877
4	3.0	90.0	3.3	3048
5	8.5	29.0	0.7	4504
6	7.0	59.0	2.3	3442
7	8.0	120.0	2.9	3451
8	5.5	49.0	0.8	8657
9	6.0	40.0	1.9	2385

[a] Rate of CO increase is the constant a in the equation $c = at$ determined by least square approximation to all data points for each house separately.

Discussion

Our review of pollution in homes and public buildings has shown consistently high levels of every kind of pollutant in enclosed "living" spaces.[10] Buildings tend to entrap pollutants that are generated indoors or seep in from outside. The unexpected high levels of CO due to cooking we observe here therefore should not come as a complete surprise. Tanaka, *et al.*,[6] Wade, *et al.*,[11] and Yates[12] reported excessively high CO levels in some kitchens. It was thought that these values were limited to instances where stoves were defective (and indeed Yates reported CO levels as high as 2500 ppm). However, we observe high exposure levels uniformly occurring in *normal* kitchens.

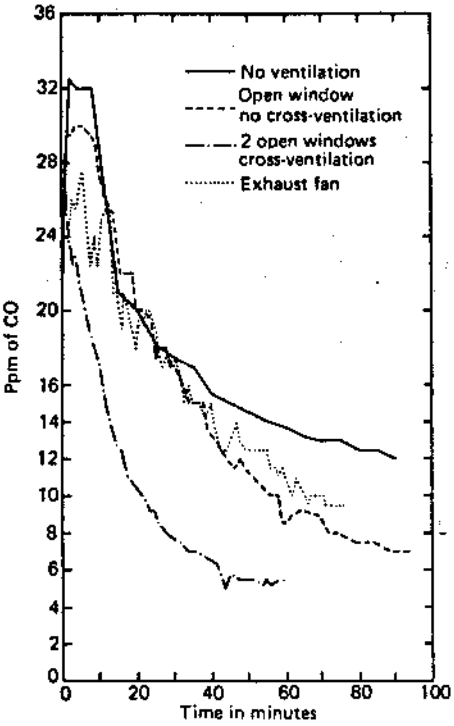

Figure 3. Disappearance of CO from the kitchen under different conditions and ventilation.

Elevated CO levels have been associated with the increased risk from a variety of diseases: ischemic heart disease and atherosclerosis,[13] increased angina pectoris pains and decreased cardiac contractability in CHD cases,[3] and impairment of survival in patients after acute myocardial infarction.[4] Also CO may be a prime contributor to respiratory disease and has been associated with fetal damage.[10]

It is interesting to compare the values observed by us under normal conditions with some of the standards used to regulate community health or to determine maximum exposure standards for workers in industry. For instance, industrial standards for many years have permitted exposures of workers to an average of 100 ppm CO over an 8-hr day. However, these standards have now been lowered in many instances to 50 ppm for the same period of time. Even more revealing are the recommended air pollution standards prepared by the Federal Interagency Task Force on Air Quality Indicators issued by the Council on Environmental Quality in September, 1976. According to the Pollution Standard Index developed by these agencies, a value of CO exceeding 34 ppm for 8 hr is considered unhealthy and a value of CO exceeding 46 ppm is considered hazardous.[14,15] Only 3 kitchens in our experiment produced CO levels after 20 min of cooking that were below the hazardous mark. The slow dissipation of CO from the house (unless efforts are made to well ventilate a house) would cause CO levels to increase after each cooling period. In households where three meals are cooked a day, the values of CO may reach even higher levels than we have observed after simulating a single cooking period.

In analyzing the effects on health of possible indoor pollutants, boys and girls from homes in which gas was used for cooking were found to have more cough, colds, bronchitis than children from homes where electricity was used.[7] The "cooking effect" appeared to be independent of the effect of age, social class, latitude, population density, family size, overcrowding, outdoor levels of smoke and sulfur dioxide and type of fuel used for heating. The investigators hypothesized that elevated levels of oxides of nitrogen arising from the combustion of gas might be the cause of increase in respiratory disease in these homes. This might well be possible. Oxides of nitrogen are known to be associated with respiratory diseases and low concentrations of NO_2 have been shown to result in increased susceptibility to disease in animals.[16] But Melia, *et al.*[17] failed to show substantial increases in NO_2 when comparing electric

Table II. Quantity of CO (ppm) after stove turned off 0, 30, and 90 minutes.

House	Room	0	30	90
001	Living	30.5	20.5	12.0
	Dining	25.5	20.2	12.0
002	Living	29.5	27.5	17.7
	Dining	37.5	28.0	18.5
003	Living	80.0	60.0	49.5
	Dining			
004	Living			
	Dining	100.0	64.0	25.0
005	Living	19.0	8.0	8.5
	Dining	22.0	11.0	9.0
006	Living	75.8	62.0	37.0
	Dining			
007	Living			
	Dining	105.0	65.0	39.0
008	Living	38.0	37.0	30.0
	Dining	34.0	34.0	28.0
009	Living	64.0	40.0	12.0
	Dining			

with gas kitchens. Also, chronic CO exposure in 50 ppm to 100 ppm may be associated with respiratory disease as well. More important, however, increases in CO may be a sign of the presence of other undesirable combustion products. It is clear that by covering gas fires with pans during cooking, air is cut off to some extent and a large variety of pollutants may be produced because of incomplete combustion.

Gas stoves are used quite frequently in North America because of the ready availability of natural gas. The use of gas stoves varies by locality and availability of gas and the comparative price of electricity to gas. There are, however, a very large number of individuals potentially exposed to gas stove produced pollutants. It is not known to what extent housewives take particular precautions to ventilate kitchens. Now, with the increased concern about the price of energy, special efforts have been made to insulate homes. One consequence of the public discussion of energy costs and the real impact of these costs on family budgets may well be a decrease in ventilation practices or in the ability to ventilate cooking and adjacent spaces. In fact, in a recent study, Kelly and Sophocoleous report fatal and near-fatal CO poisonings occurring in highly insulated homes.[8] Another area of concern is the frequent use of gas stoves as a source of heat during cold periods in slum and low standard housing. It seems to be standard practice for slum families to provide heat during cold spells in poorly heated quarters by the use of gas stoves. The effect of an all night use of gas stoves in unventilated crowded quarters should be of great concern.

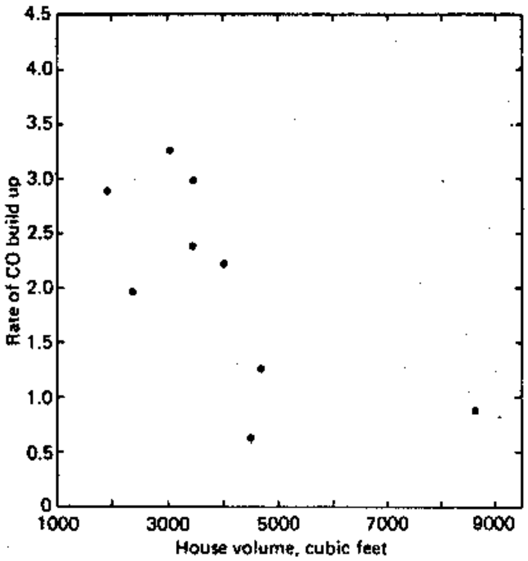

Figure 4. Scattergram of linear rate of increase of CO against volume of space in the kitchen and adjacent rooms (i.e. Effective house volume).

References

1. J. R. Goldsmith, "Contribution of motor vehicle exhaust, industry, and cigarette smoking to community CO exposure," *Ann. N.Y. Acad. Sci.* 15: 122 (1970).
2. A. G. Amiro, "CO presents public health problems," *J. Environ. Health* 32: 83 (1969).
3. W. S. Aronow, "Smoking, carbon monoxide, and coronary heart disease," *Circulation* 48: 1169 (1973).
4. J. R. Goldsmith and W. S. Aronow, "Carbon monoxide and coronary heart disease; a review," *Environ. Res.* 10, 236 (1975).
5. R. D. Stewart, "The effect of carbon monoxide on humans," *Ann. Rev. Pharmacology* 15: 49 (1975).
6. M. Tanaka, Y. Kobayashi, and S. Yoshizara, "Indoor air pollution due to domestic gas range," *Kuki Seijo* 9: 28 (1971).
7. R. J. W. Melia, C. V. Florey, D. G. Altman, and A. V. Swan, "Association between gas cooking and respiratory disease in children," *Brit. Med. J.* 2: 149 (1977).
8. J. S. Kelley and G. J. Sophocleus, "Retinal hemorrhages in subacute carbon monoxide poisoning," *J. Am. Med. Assoc.* 239: 1515 (1978).
9. F. K. Blurton and H. W. Bay, "Controlled-potential electrochemical analysis of carbon monoxide," *Amer. Laboratory* 6: 50 (1974).
10. T. Sterling and D. Kobayashi, "Exposure to pollutants in enclosed living spaces," *Environ. Res.* 13: 1 (1977).
11. W. A. Wade, W. A. Cote, and J. E. Yocom, "A study of indoor air quality," *J. Air Poll. Control Assoc.* 25: 933 (1975).
12. M. W. Yates, "A preliminary study of CO gas in the home," *J. Environ. Health* 29: 413 (1967).
13. N. J. Wald and S. Howard, "Smoking, carbon monoxide and arterial disease," *Annals Occupational Hygiene* 18, 1 (1975).
14. "A Recommended Air Pollution Index," Federal Interagency Task Force on Air Quality Indicators, Council of Environmental Quality, Washington, DC, September, 1976.
15. J. Crossland, "Reporting pollution," *Environment* 20: 29 (1978).
16. M. R. Purvis and R. Ehrlich "Effects of atmospheric pollutants on susceptibility to respiratory infection," *J. Infect. Dis.* 113: 72 (1963).
17. R. J. W. Melia, C. V. Florey, S. C. Darby, E. D. Palmes, and B. D. Goldstein, "Differences in NO_2 levels in kitchens with gas or electric cookers," *Atmos. Environ.* 12: 1379 (1978).

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