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Memorandum

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SUBJECT: Carbon monoxide (CO) emissions from a mid-efficiency, induced-draft furnace (Furnace #3): health concerns related to projected consumer exposure.

Introduction

The U.S. Consumer Product Safety Commission (CPSC) has an ongoing effort to reduce deaths and injuries resulting from accidental, non-fire related carbon monoxide poisoning (CO). Part of this effort considers the need for improvement in the safety of combustion appliances. To this end, staff initiated a project to evaluate the effects of compromised furnace vents on: furnace CO emissions, projected residential CO levels that could result under such circumstances, and, the likelihood that these projected CO levels could adversely impact consumers' health. Several furnace designs are being evaluated as part of this test program.

For mid-efficiency induced draft furnaces, the current ANSI standard for Gas Fired Central Furnaces, ANSI Z21.47, provides some degree of coverage for partial or total vent blockage scenarios in that it requires that the CO concentration in an air-free sample of flue gases shall not exceed 0.04 percent (400 ppm) when the furnace is tested in an atmosphere with a normal oxygen supply (Section 2.22, 1998). However, there are no specific requirements for a mechanism to shut off the furnace if the vent outlet is either partially or completely blocked. Also, the standard does not address the issue of disconnected vent pipes. The CPSC's Directorate for Laboratory Sciences (LS) recently issued a report concerning CO emissions from a natural gas-fueled, mid-efficiency, induced draft furnace under various "compromised-vent" test scenarios (Brown, Jordan, and Tucholski, 2000). LS staff then used selected CO emission rates derived from the LS test data to model residential CO levels that could result under different furnace use scenarios (Porter, 2000). Health Sciences (HS) staff was asked to determine whether these CO concentrations have any likely adverse impact on consumer health.

Background

The subject product of this report, a natural gas-fueled, mid-efficiency, induced draft furnace with a specified energy input rate of 110,000 Btu/hr, was tested by CPSC LS staff in a controlled environmental chamber. This furnace has only an exhaust vent pipe[1] and is equipped

[1] this furnace does not have a "direct vent" to supply fresh combustion air from the outside.

with a bimetal disc thermostat that will shut off the furnace if the thermostat temperature setting is exceeded. Due to its location near the flue outlet, the disc thermostat can only come into contact with, and be actuated by, hot flue gases when the vent pipe is blocked. After actuation, the thermostat must be manually reset before the furnace can be restarted (see page 2, Brown et al., 2000).

In addition to establishing baseline performance, CPSC LS staff investigated how furnace operation was affected by varying degrees of vent blockage (47-100% blockage) and vent blockage location, and also by a totally disconnected vent and vent disconnect location. Other important variables in the test matrix included the fuel input rate (110,000-133,000 Btu/h, i.e., up to 21% overfire), and the furnace operating conditions, which varied between an 80% "burner on" cycle and the worst-case scenario of continuous firing of the burner. The chamber test conditions were intended to replicate conditions that can occur in the field. The CO emission rates for each test run were calculated from the respective equilibrium CO concentration in the test chamber and are reported elsewhere (see Brown, Jordan and Tucholski, 2000).

Subsequently, CPSC LS staff conducted modeling analyses to predict indoor air levels of CO, based on CO emission rates derived from CPSC's empirical furnace test data. A single compartment mass balance computer model was used to estimate residential CO concentrations that could likely result from use of the furnace over a 24 hour use period, under various "compromised vent" test scenarios (Porter, 2000). LS staff's projections focus on the worst case scenario of a furnace operating in a small, airtight home (100 m^2 [240 m^3] with 0.35 air changes per hour [ACH]), however, they allow for the effects of increases in room size and/or ACH to be derived from modeled CO concentrations. The computer model also allows the user to input the cycling time of the furnace; thus, although 33% and 50% "burner-on" cycles were not specifically tested in the chamber, predicted indoor CO concentrations are presented in the modeling report. It should be noted that LS staff has acknowledged that these latter CO concentrations are calculated using CO emission rates derived from the 80% "burner on" test data, and, as such, represent conservative safety predictions since lower CO emission rates would be expected at reduced "burner on" cycles. No modeling data are presented for baseline or blocked vent scenarios because relevant LS tests did not demonstrate any elevations in CO emission rates or steady concentrations; tests results indicate that this furnace continued to vent combustion products appropriately at up to 47% vent blockage, and shutoff reliably above this vent blockage level. LS staff's projected residential CO levels for disconnected vent scenarios are presented in tabular form in the lab modeling report (see Table 2, Porter, 2000).

Health Sciences' Perspective

It is clearly established that CO interferes with oxygen uptake, delivery, and utilization by combining at least 200 times more avidly than oxygen with hemoglobin, the body's oxygen transport protein, to form carboxyhemoglobin (COHb). COHb formation is primarily a function of the CO level and duration of exposure. After 10 to 12 hours of sustained exposure to a given CO level, the % COHb level will reach an equilibrium level that is limited by that CO exposure level. Before equilibrium conditions are reached, COHb formation is greatly influenced by an exposed individual's activity level which affects the amount of air and CO taken into the lungs. As the activity level increases, the time to reach the equilibrium COHb level decreases. At high levels, CO can be a lethal asphyxiant. Levels above 20% COHb are generally considered to pose an immediate threat of permanent neurological impairment, even death, to all consumers. Sustained exposure to approximately 150 ppm CO will result in about 20% COHb at equilibrium. As a general rule, HS staff considers that keeping COHb levels from reaching 10% is protective of the majority of healthy consumers. The lowest CO exposure that can result in 10% COHb is about 65-70 ppm for at least 4-5 hours, depending on the exposed individual's activity level. However, at even lower levels, CO is reported to have more subtle effects on cardiac function, such as decreasing the onset times of exercise-induced electrocardiogram ST-segment changes and angina symptoms in some patients with coronary artery disease (CAD). These changes are indicative of myocardial ischemia and can be associated with lethal myocardial infarcts. Thus, HS staff considers CAD patients to be the population most susceptible to adverse health effects of CO exposure (Burton, 1996).

CPSC staff believes that consumer exposure to CO should be kept to a minimum, whenever feasible. Staff develops recommendations for CO limits for specific consumer products on a case-by-case basis. Staff takes into consideration the intended use of the product, consumer use patterns, relevant affected populations, technical feasibility, and overall impact of their recommendations. Previously, in association with the unvented gas space heater (UVGSH) and kerosene heater (KH) projects, CPSC's HS staff recommended that indoor CO levels should be limited to 15 ppm for 8 hours, or 25 ppm for 1 hour, as time-weighted averages. These CO exposures can potentially elevate COHb levels to approximately 2.4%, about the level associated with the earliest subtle effects of CO on cardiac function in some CAD patients. The staff's recommendations for indoor air CO limits associated with use of individual CO source products (such as UVGSHs and KHs) are generally more stringent than the limits for mandatory alarm activation of residential CO alarms[2]. The CPSC staff considers that the primary way to combat the CO hazard is to limit CO emissions from source products, particularly products that are expected to be used for extended durations, such as furnaces.

Health Science's Assessment of Projected CO Exposures

For this exposure assessment, HS staff examined LS staff's projections for the maximum 8h and 24 h-average CO exposures in the worst case modeling scenarios. The latter averages are generally slightly less than the former over the 24h modeling period used by LS staff. However, they would ultimately increase to reach the respective maximum 8h averages if the modeling period was sufficiently extended to reflect actual in-field use of furnaces. Thus, HS staff elected to base all the following CO hazard assessments on LS staff's maximum 8h averages. The LS data 8h projections are presented within this current report in Table 1. Table 1 also presents additional data to show how less extreme conditions for home size and ventilation rates can greatly reduce the projected residential CO exposure. A 75% reduction in projected CO exposures occurs when both larger sized homes (200 m^2 [480 m^3] v 100 m^2 [240 m^3]) and increased ventilation rates (0.7 ACH v 0.35 ACH) are used to model CO emission data.

[2] Current voluntary standards (UL 2034 and IAS 696) specifications for CO alarm activation are 70 ppm for 189 minutes, 150 ppm for 50 minutes, and 400 ppm for 15 minutes. Alarm resistance is required at 30 ppm for 30 days, 70 ppm for 60 minutes, 150 ppm for 10 minutes, and 400 ppm for 4 minutes. CO alarms are considered a secondary means of protecting against the CO hazard. The higher limits for CO alarm activation reflect the fact that the CO alarm is not a source product, and, that in order to maintain confidence in CO alarms, consumers/emergency responders need to be able to readily trace and address the source of CO elevations that activate an alarm signal. The CO alarm will react to CO from all sources, thus, it needs to be able to resist activation by transient elevations in outdoor CO levels and/or CO emissions from more than one normally-operating CO source product.

Baseline and Blocked Vent Conditions

As mentioned above, the empiral test data did not demonstrate any elevated CO emission rate for baseline or blocked vent test scenarios, even if the furnace was fired continuously at 133,000 Btu/hr (21% overfire). Therefore, no adverse health effects of CO would be expected under these scenarios.

Disconnected Vent Conditions

Table 1 shows data on projected 8h CO exposures that would occur when the furnace was overfired by up to 21% and the vent was disconnected in either the furnace closet or the chamber. The greatest hazard would occur when the vent disconnect occurred in the closet and the furnace was firing continuously. Under these operating conditions, and in the most extreme scenario of the tightly weatherized small home, the highest projected indoor CO levels of 129 ppm (at ~21% overfire) could result in COHb levels of about 19%. Although this COHb level is unlikely to result in lethal effects in healthy individuals, it could cause mild to severe headaches and nausea, and lasting neurological impairment is believed to be possible if the exposure is sustained for long durations. Serious life-threatening compromise of susceptible individuals, such as CAD patients, is certainly possible at this CO exposure level. However, HS staff notes that home size and ventilation rates significantly impact projected health effects; for the same CO emission rate modelled in larger, well ventilated homes, the projected indoor CO level drops to about 65 ppm, equivalent to about 10% COHb. This level may be sufficient to cause mild, barely perceptible effects in healthy individuals, but they would still be of concern to susceptible populations such as CAD patients.

The CO hazard associated with the vent disconnect in the closet decreases as the furnace firing time decreases. At both 12% and 21% overfire, there is a very slight health concern at furnace firing times between 33 and 50%, since sustained exposures to between 18 to 35 ppm are equivalent to about 3 to 5% COHb. At 80% firing times, the projected CO levels rise to between 44 and 60 equivalent to 7 to 9% COHb. All of these levels exceed the staff recommendations for other heating appliances (UVGSH and KHs). While the estimated COHb levels would not likely have any perceptible effects in healthy individuals, they would be of concern to susceptible populations, such as CAD patients.

For vent disconnects in the chamber when the furnace was fired continuously, the projected CO levels were relatively lower than respective closet disconnect projections, ranging from 62 to 99 ppm, depending on the fuel input rate. CO exposures at these levels could result in COHb levels between 9 and 14%. The higher levels could cause mild headaches and possibly nausea in healthy individuals. All levels would be of concern to susceptible populations, such as CAD patients. As would be expected, the CO hazard associated with the vent disconnect in the furnace chamber also decreased as the furnace burners cycled on and off and the "on-time" decreased. The projected CO levels ranged between 20 and 62 ppm, equivalent to between 3.3 to 9.3% which would not likely cause any perceptible effects in healthy individuals, but would be of concern to susceptible populations, such as CAD patients.

Conclusions

For the given test conditions, and when installed and maintained as intended, this particular furnace is not likely to increase residential CO concentrations to a level that would be expected to have any health impact on even the most susceptible individuals, even when the furnace vents are partially or fully blocked. Disconnected vents can result in hazardous CO exposures depending on the location of the vent disconnect and on the amount of time that the furnace burners spend in the firing mode. If the furnace vent is disconnected within the furnace closet, significant CO exposures can occur if the furnace is continuously fired. While these are unlikely to cause lethal effects in healthy individuals, serious neurological impairment could possibly result. When the vent is disconnected in the chamber area, there is a relatively reduced risk of serious CO exposure when the furnace is fired continuously.

The likelihood of serious health effects associated with vent disconnects decreases progressively as the furnace firing time decreases. However, under the given test conditions, when the furnace burners are firing for between 33 to 80% of the furnace cycle time, there is a minor to moderate health concern for vent disconnects within the closet space or chamber. The risk of any health concerns associated with CO exposure from furnaces is greatest in small, tightly weatherized homes, indeed in larger homes and/or more well ventilated homes, the projected indoor CO levels is greatly lessened. However, even in larger homes, the modeling data suggest that disconnected vents could be of concern to susceptible populations when the furnace burners operate for at least 50% of the duty cycle.

References

American National Standard/National Standard of Canada for Gas-Fired Central Furnaces, ANSI Standard No. Z21.47-1998, American Gas Association, New York, NY (1998).

Brown CJ, Jordan RA and Tucholski DR. CPSC LS memo, Furnace CO Emissions Under Normal and Compromised Vent Conditions. Furnace #3 – Mid Efficiency Induced Draft (September, 2000).

Porter WK Jr, CPSC LS memo. Indoor Air Modeling for Furnaces with Blocked or Disconnected Vents (Furnace # 3) (October, 2000).

Burton LE, CPSC HS memo. Toxicity from Low Level Human Exposure to Carbon Monoxide (7/1/96)

Table 1. Predicted 8h average indoor CO concentrations for disconnected vents in closet or chamber and various furnace operating conditions: effects of home size and ventilation rate

			Home size	100 m^2 (240 m^3)			150 m^2 (360 m^3)			200 m^2 (480 m^3)		
			ACH	0.35	0.5	0.7	0.35	0.5	0.7	0.35	0.5	0.7
Firing rate	Site of Vent	cycle	CO source				Maximum 8h average CO ppm					
Btu/hr	Disconnect	% burner on	cc/hr									
110,000	closet	100	7,360	88	65	44	58	43	29	44	33	22
110,000	closet	80	4,915	47	35	24	31	23	16	24	17	12
110,000	closet	50	4,915	29	21	15	19	14	10	15	11	7
110,000	closet	33	4,915	19	14	10	13	9	6	10	7	5
110,000	chamber	100	6,711	80	59	40	53	39	26	40	30	20
110,000	chamber	80	5,658	54	40	27	36	26	18	27	20	14
110,000	chamber	50	5,658	34	25	17	22	17	11	17	13	9
110,000	chamber	33	5,658	22	16	11	15	11	7	11	8	6
123,000	closet	100	5,906	70	52	35	46	34	23	35	26	18
123,000	closet	80	5,852	56	41	28	37	27	18	28	21	14
123,000	closet	50	5,852	35	26	18	23	17	12	18	13	9
123,000	closet	33	5,852	23	17	12	15	11	8	12	9	6
123,000	chamber	100	6,058	72	53	36	48	35	24	36	27	18
123,000	chamber	80	5,096	48	36	24	32	23	16	24	18	12
123,000	chamber	50	5,096	30	22	15	20	15	10	15	11	8
123,000	chamber	33	5,096	20	15	10	13	10	7	10	7	5
119,000	closet	100	5,447	65	48	33	43	32	21	33	24	16
119,000	closet	80	4,591	44	33	22	29	21	15	22	16	11
119,000	closet	50	4,591	27	20	14	18	13	9	14	10	7
119,000	closet	33	4,591	18	13	9	12	9	6	9	7	5
119,000	chamber	100	5,253	62	46	31	41	30	20	31	23	16
119,000	chamber	80	5,382	51	38	26	34	25	17	26	19	13
119,000	chamber	50	5,382	32	24	16	21	16	11	16	12	8
119,000	chamber	33	5,382	21	16	11	14	10	7	11	8	5
133,000	closet	100	10,816	129	95	65	85	63	43	65	48	32
133,000	closet	80	6,287	60	44	30	40	29	20	30	22	15
133,000	closet	50	6,287	37	27	19	24	18	12	19	14	9
133,000	closet	33	6,287	25	19	13	17	12	8	13	9	6
133,000	chamber	100	8,340	99	73	50	65	48	33	50	37	25
133,000	chamber	80	6,534	62	46	31	41	30	20	31	23	16
133,000	chamber	50	6,534	39	29	20	26	19	13	20	14	10
133,000	chamber	33	6,534	26	19	13	17	13	9	13	10	7