UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, DC 20207

Memorandum

August 30, 2000

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SUBJECT: Carbon monoxide (CO) emissions from a residential draft hood-equipped furnace (Furnace #1): projected consumer exposure and related health concerns.

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 consumer's health. Several furnace designs are being evaluated as part of this test program.

The current ANSI standard for Gas Fired Central Furnaces requires that draft hood-equipped furnaces incorporate a "blocked vent shutoff system" to shut down the furnace when the vent is totally blocked (ANSI Z21.47, section 2.19, 1998). However, the standard has no provisions for partially blocked vents or disconnected vents. The CPSC's Directorate for Laboratory Sciences (LS) recently issued a report concerning CO emissions from a natural gas-fueled, draft hood-equipped 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 test 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, draft hood-equipped furnace with an energy input rate of 100,000 Btu/h, was tested by CPSC LS staff in a controlled environmental chamber. In addition to establishing baseline performance, staff investigated how furnace operation was affected by varying degrees of vent blockage (50-100% blockage), and by a totally disconnected vent. Other important variables in the test matrix included the fuel input rate, (from 100,000 to 123,000 Btu/h, i.e., up to 23% 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. They are reported elsewhere, along with the performance of the "blocked vent shutoff system" where relevant (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 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 with 0.35 air changes per hr [ACH]), however, they allow for the effects of increases in room size and/or ACH to be derived from modelled 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 modelling 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. LS staff's projected residential CO levels for blocked vent, disconnected vent and reduced combustion air scenarios, are presented in tabular form in the lab report (see Tables 2, 3, and 4, 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[1]. 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 modelling scenarios. The latter averages are generally slightly less than the former over the 24h modelling period used by LS staff. However, they would ultimately increase to reach the respective maximum 8h averages if the modelling 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 and 24h projections are presented within this current report in Tables 1, 2, and 3. These tables also present 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 v 100 m^2) and increased ventilation rates (0.7 ACH v 0.35 ACH) are used to model CO emission data.

Baseline Conditions

When the furnace was operated with intact, unoccluded vents, CO emission rates were extremely low, and there was negligible impact on projected residential CO concentrations, even if the furnace was 23% overfired and running continuously (See Appendix G, Table G1, Brown, Jordan, and Tulcholski, 2000).

Blocked Vent Conditions

Table 1 indicates that with continued firing at the specified fuel input rate, there was minimal effect on projected CO exposure, even with 100% vent blockage. However, it is clear that continued firing of the furnace at increased input rates is of greatest health concern. A maximum 8h average exposure of 751 ppm CO was projected for 10% overfiring with 100% vent blockage, and 2,527 ppm was projected for 23% overfiring with 90% vent blockage. These CO exposures are considered catastrophic since they would be expected to maintain COHb at lethal levels for at least 8 hours, (a minimum of 56 % COHb based on predictions made using the Coburn, Forster Kane [CFK] equation). Other predictions for the 23 % overfire - 90% vent

[1] 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.

blockage scenario show that decreased burner time reduces the projected CO hazard. Nonetheless, the CO exposures are still considered capable of causing lethal or permanent injury since about 20-45% COHb is projected for 8h exposures to 150-500 ppm CO.

There is some concern for the most susceptible individuals at other less severe 10% overfire test conditions. The predicted CO exposures (31, 41, and 47, and-76 ppm) exceed the HS recommendations for residential CO exposures for other heating appliances (UVGSH and KHs) and could result in elevations of about 5-11% COHb. Little or no perceptible effect would be expected in healthy individuals at these CO exposures since COHb levels would just reach about 11% for the 76 ppm exposure level.

Disconnected Vent Conditions

Table 2 shows that a disconnected vent would result in catastrophic CO exposures when the furnace is 23% overfired. With the burner operating 80%-100% of the time, CO exposure levels above 800 ppm would result in COHb levels exceeding 57%. With the burner operating 33-50% of the time, projected COHb levels would be about 37-47% for CO levels between 345-519 ppm, which could certainly cause permanent impairment or even lethal injury. At firing rates below 123,000 Btu/h, there is a dramatically reduced concern for adverse health effects. Healthy individuals will not likely be affected, but for CO exposure levels between 18-37 ppm (equivalent to about 3–6% COHb) there could be some adverse impact on the most susceptible individuals.

Reduced Combustion Air with a Partially Blocked or Disconnected Vent

Table 3 shows some limited data on projected CO exposures for the combined effects of reduced combustion air with either partially blocked or disconnected vents. Again, the data indicate that the most hazardous CO exposures occur when the furnace is 23% overfired. When the vent is disconnected, the CO hazard increases as the burner operating time increases. All the projected CO levels for the 23% overfire-reduced air conditions are considered catastrophic exposures, since they would elevate COHb levels to at least 55%, which is likely to be lethal. When the furnace is 10% overfired and the vent partially blocked (80% blockage), only the continuous burner operation would be expected to affect healthy adults, with about 23% COHb expected at the 177 ppm exposure level. The remaining scenarios would be of some concern to susceptible individuals

Conclusions

When installed and maintained as intended, the draft hood-equipped 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. However, when the furnace vents are partially or fully blocked, or disconnected, catastrophic CO exposures can occur when the furnace is overfired by 23%. Even 10% overfire can result in lethal CO exposures if the furnace burner runs continuously when the vent is totally blocked. The risk of such catastrophic CO exposures is greatest in small, tightly weatherized homes.

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 #1 – Draft Hood Equipped, (August, 2000).

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

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

Table 1. Predicted 8h and 24h average indoor CO concentrations for various blocked vent scenarios and furnace operating conditions: effects of home size and ventilation rate

			Home size	100 m^2			150 m^2			200 m^2		
			ACH	0.35	0.5	0.7	0.35	0.5	0.7	0.35	0.5	0.7
Firing rate Btu/hr	VENT % block	cycle % burner on	CO source cc/hr	Maximum 8h average CO ppm								
100,000	100	100	1046	12	9	6	8	6	4	6	5	3
100,000	100	80	373	4	3	2	2	2	1	2	1	1
100,000	100	50	373	2	2	1	1	1	1	1	1	1
100,000	100	33	373	2	1	1	1	1	0	1	1	0
110,000	100	100	63178	751	556	376	496	367	248	376	278	188
110,000	90	100	3428	41	30	20	27	20	13	20	15	10
110,000	100	80	7998	76	56	38	50	37	25	38	28	19
110,000	100	50	7998	47	35	24	31	23	16	24	18	12
110,000	100	33	7998	31	23	16	21	15	10	16	12	8
123,000	90	100	212500	2527	1870	1263	1668	1234	834	1263	935	632
123,000	90	80	41297	392	290	196	259	192	129	196	145	98
123,000	90	50	41297	245	181	122	162	120	81	122	91	61
123,000	90	33	41297	162	120	81	107	79	53	81	60	40
123,000	80	100	41105	489	362	244	323	239	161	244	181	122
123,000	80	80	17582	167	124	84	110	82	55	84	62	42
123,000	80	50	17582	104	77	52	69	51	34	52	39	26
123,000	80	33	17582	69	51	34	45	34	23	34	25	17
				Maximum 24h average CO ppm								
100,000	100	100	1046	11	8	6	7	5	4	6	4	3
100,000	100	80	373	3	2	2	2	2	1	2	1	1
100,000	100	50	373	2	1	1	1	1	1	1	1	1
100,000	100	33	373	1	1	1	1	1	0	1	0	0
110,000	100	100	63178	663	490	331	437	324	219	331	245	166
110,000	90	100	3428	36	27	18	24	18	12	18	13	9
110,000	100	80	7998	67	50	34	44	33	22	34	25	17
110,000	100	50	7998	42	31	21	28	21	14	21	16	11
110,000	100	33	7998	28	21	14	18	14	9	14	10	7
123,000	90	100	212500	2229	1649	1114	1471	1088	735	1114	825	557
123,000	90	80	41297	346	256	173	229	169	114	173	128	87
123,000	90	50	41297	217	161	108	143	106	72	108	80	54
123,000	90	33	41297	144	107	72	95	70	48	72	53	36
123,000	80	100	41105	431	319	216	285	211	142	216	160	108
123,000	80	80	17582	148	109	74	97	72	49	74	55	37
123,000	80	50	17582	92	68	46	61	45	30	46	34	23
123,000	80	33	17582	61	45	31	41	30	20	31	23	15

Table 2. Predicted 8h and 24h average indoor CO concentrations for disconnected vent scenarios and various furnace operating conditions: effects of home size and ventilation rate

			Home size	100 m^2			150 m^2			200 m^2		
			ACH	0.35	0.5	0.7	0.35	0.5	0.7	0.35	0.5	0.7
Firing rate Btu/hr	% Vent disconnect	cycle % burner on	CO source cc/hr	Maximum 8h average CO ppm								
100,000	100	80										
110,000	100	100	1510	18	13	9	12	9	6	9	7	5
110,000	100	80	947	9	7	5	6	4	3	5	3	2
100,000	100	50	947	6	4	3	4	3	2	3	2	1
100,000	100	30	947	4	3	2	2	2	1	2	1	1
112,000	100	100	3136	37	28	19	25	18	12	19	14	9
112,000	100	80	1918	18	13	9	12	9	6	9	7	5
112,000	100	50	1918	11	8	6	8	6	4	6	4	3
112,000	100	30	1918	8	6	4	5	4	2	4	3	2
123,000	100	100	223170	2654	1964	1327	1751	1296	876	1327	982	663
123,000	100	80	98700	938	694	469	619	458	309	469	347	234
123,000	100	50	98700	585	433	293	386	286	193	293	217	146
123,000	100	30	98700	387	286	194	255	189	128	194	143	97
				Maximum 24h average CO ppm								
100,000	100	80										
110,000	100	100	1510	16	12	8	10	8	5	8	6	4
110,000	100	80	947	8	6	4	5	4	3	4	3	2
100,000	100	50	947	5	4	3	3	2	2	3	2	1
100,000	100	30	947	3	2	2	2	2	1	2	1	1
112,000	100	100	3136	33	24	16	22	16	11	16	12	8
112,000	100	80	1918	16	12	8	11	8	5	8	6	4
112,000	100	50	1918	10	7	5	7	5	3	5	4	3
112,000	100	30	1918	7	5	3	4	3	2	3	2	2
123,000	100	100	223170	2340	1732	1170	1545	1143	772	1170	866	585
123,000	100	80	98700	828	612	414	546	404	273	414	306	207
123,000	100	50	98700	519	384	259	342	253	171	259	192	130
123,000	100	30	98700	345	255	172	228	168	114	172	128	86

Table 3. Predicted 8h and 24h average indoor CO concentrations for reduced combustion air and various furnace operating conditions: effects of home size and ventilation rate

			Home size	100 m^2			150 m^2			200 m^2		
			ACH	0.35	0.5	0.7	0.35	0.5	0.7	0.35	0.5	0.7
Firing rate Btu/hr	Vent status	cycle % burner on	CO source cc/hr	Maximum 8h average CO ppm								
110,000	80% blocked	100	14884	177	131	89	117	86	58	89	65	44
110,000	80% blocked	80	4643	44	33	22	29	22	15	22	16	11
110,000	80% blocked	50	4643	28	20	14	18	13	9	14	10	7
110,000	80% blocked	33	4643	18	13	9	12	9	6	9	7	5
123,000	disconnected	80	185404	1762	1304	881	1163	860	581	881	652	440
123,000	disconnected	50	185404	1099	814	550	726	537	363	550	407	275
123,000	disconnected	33	185404	727	538	363	480	355	240	363	269	182
	Maximum 24h average CO ppm											
110,000	80% blocked	100	14884	156	116	78	103	76	52	78	58	39
110,000	80% blocked	80	4643	39	29	19	26	19	13	19	14	10
110,000	80% blocked	50	4643	24	18	12	16	12	8	12	9	6
110,000	80% blocked	33	4643	16	12	8	11	8	5	8	6	4
123,000	disconnected	80	185404	1555	1151	777	1026	759	513	777	575	389
123,000	disconnected	50	185404	974	721	487	643	476	321	487	360	243
123,000	disconnected	33	185404	648	479	324	427	316	214	324	240	162