

Carbon Monoxide Production in Compartment Fires - Full-Scale Enclosure Burns  
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### Introduction

Recent studies attribute a large percentage of fire injuries and deaths to the generation of carbon monoxide (CO) [1-3] and indicate that in roughly two-thirds of the fire deaths the fire victims have fatal or incapacitating levels of carboxyhemoglobin in their blood. A series of natural-gas fires within reduced- and full-scale rooms have been designed to improve the understanding of and develop a predictive capability for CO formation in compartment fires. The findings will be used in realistic fire models and in the development of strategies for reducing the number of deaths attributed to carbon monoxide.

The full-scale room burns described by this paper extend the earlier work conducted in a reduced-scale (2/5ths) enclosure (RSE) [4]. The Full-Scale Enclosure (FSE) experiments were designed to examine whether the gas species and temperatures observed in the RSE could be used to predict the conditions in a FSE. While over 140 fires with heat release rates (HRRs) ranging from 7 to 650 kW were burned within the RSE, a more limited series of twelve fires ranging from 450 kW to 3500 kW were completed within a full-scale version of the standard room. Fires of greater than 200 kW and 1400 kW HRR created post-flashover conditions within the RSE and FSE, respectively. The RSE experiments had demonstrated that for flashed-over conditions, the upper layer was nonuniform in carbon monoxide and carbon dioxide concentrations as well as upper-layer temperature.

### Experimental

The FSE is a standard room, 2.44 m wide by 2.44 m tall by 3.67 m deep with a 0.76 m wide by 2.03 m tall door centered at the bottom of the front wall as described by ISO/DIS 9705 [5]. The room consists of a sheet metal stud framework which is lined with three layers of 1.27 cm thick gypsum wallboard and a single layer of 1.27 cm thick calcium-silicate board. The FSE was instrumented with thermocouple trees located in the front and rear of the enclosure. Cooled and uncooled probes were positioned at different locations to sample the upper combustion layer, lower layer, and outside the doorway. The FSE was located under a large instrumented exhaust hood which allowed oxygen calorimetry and gas analysis to be performed on the exhaust gases from the enclosure. Doorway mass flows were measured through the door in two ways using a pressure probe and aspirated thermocouples located in the doorway. The burner was centered in the enclosure and each fire ranged from 15 to 20 minutes in duration.

### Results and Discussion

Figure 1 shows a plot of CO concentrations versus time for the rear in the upper layer for several heat release rates. At 1400 kW HRR, the CO concentration begins to rise and peaks at about 0.5% in the front (not shown) and rear. As the HRR exceeds 2000 kW, the CO concentration quickly reaches 3 % and gradually peaks over 6 % in both the front and rear of the upper layer. CO concentrations are slightly higher in the front than in the rear of the enclosure. Figure 2 shows O<sub>2</sub> concentrations for the fires ranging from 450 kW to 3500 kW. The O<sub>2</sub> concentration drops to near zero at 1200 kW and remains near zero for all higher HRR. Typically the depletion of oxygen occurred more quickly in the rear of upper layer than the front portion.

Since temperatures in the upper layer exceeded the range of chromel-alumel thermocouples, a pair of platinum-rhodium thermocouples were installed for a 2300 and 3500 kW fires. In the 3500 kW fire, front and rear temperatures peaked at 1200 C and 950 C, respectively. Slightly higher temperatures were observed in the front and rear, 1300 C and 1000 C, respectively, for a 2300 kW fire. As was observed in the reduced-scale work, the front portion of the upper layer in the FSE was typically hotter than the rear. The reduced-scale study hypothesized that an interaction between the plume and upper layer was causing additional air to be injected directly into the upper layer. This additional oxygen reacted with unburned fuel in the upper

layer to form additional CO while releasing energy which increased the temperature in the front portion of the upper layer.

Different scaling parameters including plume entrainment, fuel mass flow rate, ceiling jet, volume, surface area, and ventilation rate were used to scale-up the fire size from the reduced-scale work. Using a ventilation rate parameter,  $Ah^{1/2}$  [6], seemed to produce the best results.

### Conclusions

The FSE burns generated significantly higher upper-layer carbon monoxide concentrations than observed in the RSE burns. The upper layer was more uniform in terms of gas species concentrations than in the RSE. The front and rear of the upper layer was quickly depleted of O<sub>2</sub> for HRR > 1200 kW. Carbon monoxide concentrations of about 6 % were measured in the front and rear of the FSE during higher HRR fires. These CO levels are two times higher than the concentrations observed in the reduced-scale enclosure burns [4] and about three times higher than reported by previous researchers conducting idealized hood experiments [7-9]. Temperatures in the upper layer of the FSE appeared to be significantly higher than in the RSE, but the front portion of the upper layer in both the FSE and RSE was significantly higher than the rear. The physical and chemical mechanisms which produce the high concentrations of CO and high temperatures in the RSE also appear to be functioning in the FSE burns. Correlations and/or models need to be developed that include the production of carbon monoxide in high temperature vitiated regions of compartment fires.

### REFERENCES

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