

# AN ENGINEERING ALGORITHM FOR THE ESTIMATION OF CARBON MONOXIDE GENERATION IN ENCLOSURE FIRES

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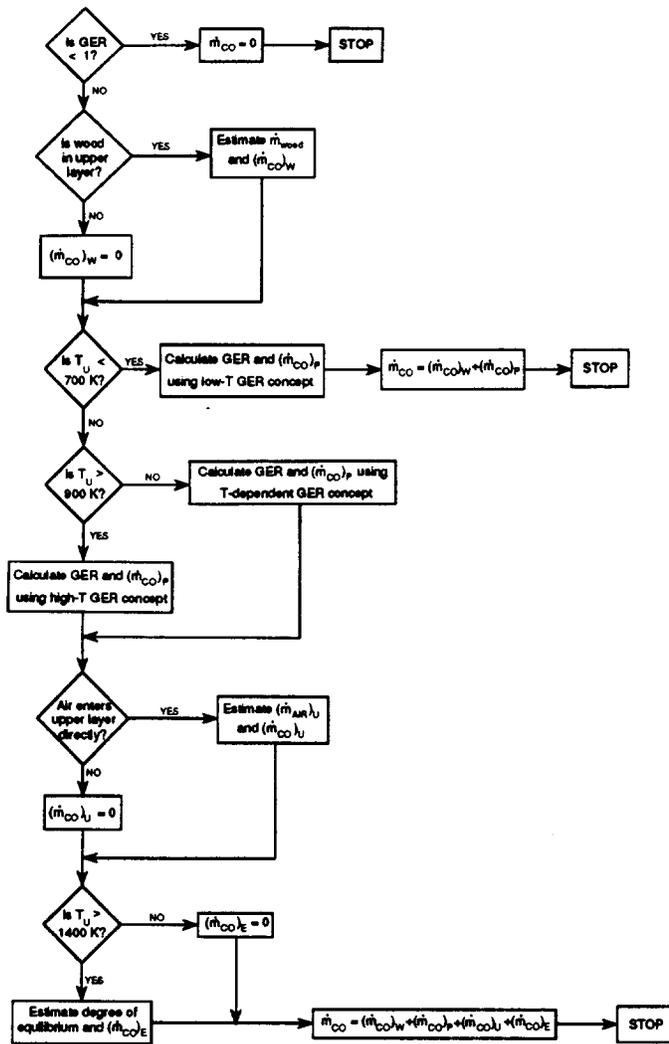
Roughly two thirds of all deaths resulting from enclosure fires can be attributed to the presence of carbon monoxide (CO) [1],[2] which is the dominant toxicant in fire deaths [3]. A long-term program (Carbon Monoxide Production and Prediction Project) at the Building and Fire Research Laboratory is seeking to develop an understanding of and predictive capability for the generation of CO in enclosure fires [4].

During the past five years a great deal of research has been performed which forms the basis of an engineering approximation for estimating the generation of CO within a burning enclosure. A detailed summary of much of the work through 1993 is available [5].

It had previously been shown that the major products of combustion measured in hoods located above open fires in the laboratory are strongly correlated with the global equivalence ratio (GER, defined as the ratio of masses derived from fuel and air normalized by the ratio for stoichiometric burning) for the gases trapped in the hood [6],[7]. The existence of these correlations has been termed the GER concept [5]. Much of the recent research effort was focused on answering the question: Can the generation behavior of CO observed in hood experiments designed to model two-layer burning be extended to predict CO generation in actual enclosure fires? Unfortunately, tests in reduced-scale [8] and full-scale [9] enclosures have shown that the GER concept alone is insufficient to predict the observed CO concentrations. Actual concentrations are found to be higher than predicted by the GER concept [5].

The various investigations have identified four mechanisms for the generation of CO during enclosure fires:

1. **Quenching of a turbulent fire plume upon entering a rich upper layer.** This is the mechanism considered by the hood experiments [6],[7]. It should be noted that while the products of combustion correlate well with the GER in the hood experiments, the concentrations of products observed have been found to vary over a upper-layer temperature range of 700-900 K [5],[7].
2. **Mixing of oxygen directly into a rich, high-temperature upper layer.** Detailed kinetic modeling has shown that if oxygen is introduced directly into a rich upper layer having temperatures greater than 800 K, that reaction with fuel will generate primarily CO [5],[10],[11]. Evidence from fire tests in a reduced-scale enclosure [5],[8],[12] indicates that direct mixing of air into and subsequent reaction of rich upper-layer mixtures does occur leading to higher concentrations of CO than predicted by the GER concept.
3. **Approach to full-equilibrium combustion product concentrations in a rich, high-temperature upper layer.** Equilibrium concentrations of CO for rich upper layers and temperatures greater than 900 K approach 16% for a GER of 3. Normally, these concentrations are not observed because the mixtures are kinetically frozen. However, it has been shown that these rich mixtures do begin to react towards equilibrium concentrations for temperatures on the order 1400 K [11]. If these high temperatures occur for underventilated fires, the concentrations of CO can increase dramatically.
4. **Pyrolysis of wood in high-temperature, vitiated environments.** Experiments in the reduced-scale enclosure have shown that wood located in a high-temperature, highly vitiated upper layer undergoes pyrolysis which efficiently generates CO [13]. The majority of pyrolyzed wood carbon is lost as



a roughly 1:1 mixture of CO and CO<sub>2</sub>. Depending on the flow rate of the upper layer gases, the resulting increases in CO concentration can be quite large.

One should keep in mind that other pathways for the generation of CO may exist.

The algorithm shown at the left is based on these findings. It is designed to guide engineering calculations of CO generation rate in enclosure fires. The various symbols are defined as follows.  $\dot{m}$  with a subscript are mass flow rates or reaction rates for the indicated species. The subscripts P, U, E, and W refer to generation of CO by processes 1-4 listed above, and  $T_U$  is a measure of the average upper-layer temperature.

Engineering estimates will be necessary for many of the parameters required to use this algorithm. Despite the uncertainty in such estimates, this approach should provide much improved predictions of CO generation in enclosures during underventilated burning than have been possible in the past.

Once generation rates are available within the enclosure, it will be necessary to model the reaction behavior and transport of the gases outside of the enclosure. This is the subject of ongoing research.

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