CORRELATION OF SMOKE DEVELOPMENT IN ROOM TESTS WITH CONE CALORIMETER DATA FOR WOOD PRODUCTS

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Abstract

A direct proportionality has been found between the smoke extinction area (SEA) for smoke of room linings and the SEA as measured in the cone calorimeter (ISO5660). The room test scenario (ISO9705) considered was the propane ignition burner at the corner with a 100/300 kW program and the specimen lined on the walls only. The mixing of smoke from propane and lining flames in the hot vitiated ceiling layer and within the exhaust system was modeled by adding contributions from heat release rates of propane and linings separately as a function of time. With overventilation and flaming generally existing in the room, the best correlation was a value of 0.3 for the ratio of lining SEA (= $EHC*RSP_1/RHR_1$) to the peak SEA measured in the cone calorimeter of a horizontal specimen exposed to the flux of 35 kW/m^2 during flaming. The test room linings in the order of increasing value of SEA were determined as plywood (including fire-retardant treated (FRT)), lumber, wood composite, and FRT polyurethane foam.

BACKGROUND AND INTRODUCTION

The literature contains various correlations between large-scale smoke measurements and those of small scale. An extensive review by Quintiere (1982) summarizes various correlations of smoke and also their shortcomings. Quintiere considered the state of the art in static smoke tests in various-sized smoke density chambers. Through several comparisons of available data, Quintiere demonstrated the quite poor correlation between any given test method for smoke and a large-scale test result. He pointed out the need to evaluate particle optical density and smoke particulate fraction dynamically and to account for the effect of surface heat flux,

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specimen orientation, or global oxygen concentration on smoke production. These factors of smoke were investigated by Babrauskas and Mulholland (1987) using the cone calorimeter. They found that the specific extinction area, σ_s (extinction coefficient divided by mass concentration of smoke) as an intrinsic property of flaming smoke was essentially a constant for a given material regardless of flux and orientation. Recently, using a more precise measurement apparatus, Mulholland and Choi (1998) demonstrated the nearly universal value for as as 8.3 ± 1.0 m^2/g for the post-flame smoke produced from overventilated fires and measured with a laser using a red wavelength of 632.8 nm. In a classic study with composite materials, Ou and Seader (1978) obtained s_s values of 7.6 m^2/g for flaming conditions and 4.4 m^2/g for smoldering conditions. The measurement of mass concentration of smoke was based on accumulation of soot deposit on a collector, whereas a dynamic measurement of smoke is best done with light extinction measurements. The fundamental relationship for specific extinction area of a single pure fuel is

$$k = s_s \rho_s \tag{1}$$

Mass conservation of post-combustion smoke is given by the continuity equation:

$$\rho_s \quad \dot{V} = \chi_s \ \dot{m}_f \tag{2}$$

The effect of air entrainment above the fire was to increase the volumetric flow rate, promote turbulent mixing, and minimize soot particles settling out or depositing on cold walls. The mass concentration of smoke then decreased, maintaining the validity of the continuity equation. Combining the previous two equations results in the basic smoke equation for use in either the room test or cone calorimeter:

$$RSP = k\dot{V} = \sigma_s \ \chi_s \ \dot{m}_s = \sigma_s \ \chi_s \ MLR \tag{3}$$

Therefore, the SEA, computed as the ratio RSP/MLR, is the product of two fundamental smoke parameters, specific extinction area and smoke mass fraction of the fuel mass loss. According to results plotted by Tewarson (1995) for various fuels, the smoke mass fraction per unit fuel mass is constant for global equivalence ratio less than 0.5 and increases dramatically as global equivalence ratio reaches unity. This implies that as long as the flame is clearly over-ventilated, as it is in the cone calorimeter, the large-scale furniture calorimeter, and the room tests during preflashover, the SEA should be constant and independent of the different scales of fire tests or levels of radiant flux. This was the situation examined by Mulholland et al. (1986) and Babrauskas and Mulholland (1987). For four fuels, which were PMMA, rigid polyurethane foam, n-Heptane pool, and Prudhoe Bay crude oil, SEAs were indeed relatively independent of bum time, radiant flux, and the scale of fire (3 to 300 kW). On the other hand, for three fuels, which were wood, furniture cushions, and propane, SEAs were not independent of time and the averaged SEA generally increased with radiant flux. However, Mulholland and others found good correlation between the small- and large-scale SEA if the specific mass loss rate of the fuel is the same at both scales. Also, for upholstered furniture, Babrauskas and Mulholland found that the furniture calorimeter peak SEA is one-third that of the cone calorimeter peak SEA for specimens tested horizontally at 25 kW/m^2.

Delichatsios (1993) suggests a breakthrough in establishing quantitative relationships between soot concentrations with the smoke-point height of a laminar diffusion flame for a given fuel. Using smoke yield data for turbulent buoyant jet flames and making the observations of proportionality of soot yield with soot mass concentration and of smoke-point height (the height at which smoke begins to appear) with RHR at smoke-point, Delichatsios derived the following formula for various gas, liquid, and solid fuels as

$$\chi_s = 0.20\ (S + 1) / \dot{Q}_{sp} \tag{4}$$

For extrapolation to the room tests, we provide the identifications, $S + 1 = r_1 / Y_0$, $\Delta h_c / r_f \approx 13.1$kJ/g, $\sigma_s = 8.3$ m^2/g, and $RHR = \Delta h_c\ MLR$. Substituting these equations along with Equation (4) into Equation (3) we derive the alternative formula

$$RSP = \frac{RHR}{7.89\ Y_0\ \dot{Q}_{sp}} \tag{5}$$

The implication is that by measuring the rate of heat release at the smoke-point, the RSP for any scale RHR is computed from Equation (5). Since RSP should be proportional to either MLR or RHR, it may be helpful to examine the ratio of total smoke production to either the mass loss or total heat release.

The work of Ostman and Tsantaridis (1991, 1993) and Heskestad and Hovde (1999) represents the first attempts to correlate smoke production from the cone calorimeter with that of room tests. The room burn scenario was a 100/300 kW comer ignition burn with the room linings on both walls and ceiling. The specimen in the cone calorimeter was horizontal and exposed to the radiant flux of 50 kW/m^2. These researchers have used the various relationships suggested and found some unexpected correlation of smoke. Ostman and Tsantaridis (1993) found that just RSP or total smoke production should be correlated between the two scales. Heskestad and Hovde (1999) found that the RSP corresponding to RHR = 400 kW correlates well with the ratio of total carbon monoxide production to total heat release and with time difference between maximum heat release and ignition. They chose RHR = 400 kW as a reference point because it seemed to be a compromise between minimizing the effect of the propane ignition burner and avoiding the high errors related to the rapid RHR rise just before flashover, They also pointed out that the delayed time mixing of smoke in the ceiling layer makes RSP not a true instantaneous measure like the cone calorimeter. Janssens (199 1) computed the SEA for the room by multiplying effective heat of combustion (EHC) (measured in cone calorimeter) by total smoke production and dividing by the total heat release of the lining. He asserted that the propane burner contributes very little smoke, so then its total heat release should be subtracted from the total heat release.

In this work, recent advancements in data acquisition and processing as well as experimental data will be used to suggest an improved smoke analysis. Next, our list of tested wood products (and a single polyurethane foam) is provided along with a discussion of the variations in the effective heat of combustion and SEA as a function of time, radiant flux, and orientation in the cone calorimeter. We then note that the smoke-point phenomena observed in the cone calorimeter complicated the interpretations of SEA for charring materials such as wood products. Additional complications of wood combustion included simultaneous flaming and glowing (Ou and Seader 1978, Dietenberger 1999). As a result, in the next section, a simple formula for RSP of each room test shows linear variations with propane and lining RHR. Although we have found this relationship for 17 different materials, only results for FRT Douglas-fir plywood, Douglas-fir plywood (ASTM), FRT polyurethane foam, and hardboard are shown. In the last section, we derive the various correlations between a smoke parameter of the room test and the corresponding smoke parameter of the cone calorimeter.

SMOKE MODEL FORMULATION

Of the various schemes for accounting for separate pyrolysis sources of smoke production, the one developed by Ou and Seader (1978) was the most successful by using an additivity relationship to predict smoke production. That is, smoke properties of homogeneous materials were first obtained, and then various combinations of these materials, in composite materials, were tested resulting in a synergistic smoke property that was attributed to each material by their mass fraction portion. In the room tests, there are four smoke sources, which are the propane flame and the three phases of wood smoking from smoldering. flaming, and afterglow. The propane flame is absent in the cone calorimeter. However, one factor not accounted for by Ou and Seader, as well as other researchers, is the effect of smoke-point that changes smoke production during wood flaming. An additivity relationship that is applicable to all these situations is to simply use the addition of the extinction coefficients from different sources as in

$$k = \sum_i k_i = \sum_i \sigma_{s,i} \, \rho_{s,i} \tag{6}$$

Combining this equation with Equation (2) of each smoke source, we obtain the fundamental formula for the rate of smoke production as

$$RSP = k\dot{V} = \sum_i \sigma_{s,i} \, \chi_{s,i} \, \dot{m}_{f,i} \tag{7}$$

Furthermore. the mass gasification rate of each source i can be determined as their measured rate of heat release divided by effective heat of combustion or as their mass fraction multiplied by a measured overall mass loss rate. Thus, for the propane, we directly measured the mass gasification rate using the signal from the mass flow controller. Then we applied a double low-pass digital filter. the first with a time constant of 18 seconds to simulate transient mixing of propane combustion products in the hot ceiling layer and exhaust pipes and the second with a time constant of 10 seconds to mimic the time response of gas analysis or laser smoke system (Dietenberger et al. 1995). The propane's contribution to RHR is its "digitally filtered" mass gasification rate multiplied by the heat of combustion value of 46.36 kJ/g. Therefore, the lining's RHR is the measured RHR minus the propane's RHR.

The presence of the propane ignition burner tends to minimize smoking due to smoldering or afterglow. However, the variation of radiant flux on wood products has a significant effect on the smoke mass fraction in relation to the smoke-point. To illustrate the phenomena, some observations about the smoke-point from measurements in the cone calorimeter are the following. First, the wood typically has an initial RHR peak that rapidly decreases to an approximate RHR plateau because of the insulating effect of the char layer. There is usually a second RHR peak due to termination of the thermal wave in a finitely thick specimen. During these changes, the effective heat of combustion remains constant. Curiously enough, the smoke-point occurs at a RHR between the peak and the plateau at most radiant flux levels. For most materials, the smoke-point RHR is independent of heat flux or surface orientation, as one might surmise from Equation (5). The second observation is the SEA for many materials rises rapidly after the smoke-point and levels out at a constant value as RHR increases further. The third observation is that the peak and plateau levels of the wood's RHR profile generally increase with imposed heat flux. Thus, at high fluxes, such as 50 or 65 kW/m^2, the RHR at the plateau level rises above the smoke-point, thereby resulting in a jump increase in the averaged SEA compared with that of the low flux levels.

The significance is that in our analytical model of fire spread in the room (Dietenberger and Grexa 1999) we determined that the radiant flux should be around 35 kW/m^2 on a horizontal specimen to use a specific RHR profile from the cone calorimeter to predict the fire growth in the room. Other researchers had preferred the level at 50 kW/m^2 because then at least all materials will ignite and provide a stable flame in the horizontal orientation. All our materials, including the treated ones, could be ignited within about a minute and burn at flux of 35 kW/m^2. Given that the change in the propane's RHR from 100 to 300 kW at 10 min will increase the imposed heat flux on the burning wood, the correlation for RSP must reflect the factor of the averaged SEA increasing with heat flux. Therefore, Equation (7) is applied to the room tests as

$$RSP = \frac{\sigma_p \chi_p}{\Delta h_{c,p}} RHR_p + \sum_i \frac{\sigma_{s,i} \chi_{s,i} f_i}{e_i} \times \frac{RHR - RHR_p}{EHC_{cone}} \tag{8}$$

where f; represents the fractions of the room lining identified as smoldering, flaming, or glowing, and e; is the ratio of actual heat of combustion of a burning element to the effective heat of combustion measured in the cone calorimeter. Due to smoke-point effects, the averaged SEA of the wall linings would correlate at least linearly to the propane RHR:

$$SEA_l \equiv EHC_{cone} RSP_l / RHR_l \equiv \sum_i \frac{\sigma_{s,i} \chi_{s,i} f_i}{e_i} = a + b\, RHR_p \tag{9}$$

Next we show that Equations (8) and (9) are sufficient to represent all our room tests.

CORRELATION FOR RATE OF SMOKE PRODUCTION IN TEST ROOMS

Table 1 shows the list of materials used in the room tests. A description of these materials has been given by Grexa (1996). The value for the term $\sigma_p\ \chi_p\ /\ \Delta h_{c,p}$ was found to be 0.123 m^2 MJ for all tests and therefore is not listed in the table. With the known values for flaming SEA and propane's heat of combustion, the propane smoke mass fraction is derived as 0.69x10 m^3. This is much smaller than reported for propane post-flame plume and is probably due to some wall effect on the propane flame. However, Table 1 lists the other derived constants of the regression as the terms a / EHC_{cone}, and b / EHC_{cone}. In many cases, b is indeterminate (—) because the propane RHR is not changing during positive values of RSP. These constants are converted to the ratio, RSP_1 / RHR_1, using Equation (9) and are listed in the next column of Table 1. It is also used in connection with Equation (5) for predicting the RHR at smoke-point, which is shown as the last column in Table 1. Figures 1 to 4 show the regression results with the representative materials: FRT Douglas-fir plywood, Douglas-fir plywood (ASTM), FRT polyurethane foam, and hardboard. In each case, the predicted RSP from Equation (8) follows the experimental RSP as a function of time right up to the point of flashover. Figures 1 and 4 demonstrate the validity of the additivity between the lining and propane contributions to the RSP.

CORRELATION WITH SMOKE PARAMETERS OF CONE CALORIMETER

At least six identical materials were tested in three different cone calorimeters. These materials are Douglas-fir plywood, redwood, southern pine plywood particle board oriented strandboard, and FRT plywood. These six materials were tested at National Institute of Science and Technology (NIST) in the vertical orientation. in anticipation of the wall linings being vertically mounted. All materials, including those beyond the original six, were tested in the horizontal orientation at USDA Forest Service, Forest Products Laboratory (FPL) in Madison, Wisconsin, USA and at State Forest Products Research Institute (SFPRI) in Bratislava, Slovak Republic. At radiant fluxes of less than 30 kW/m^2, all of the cone calorimeter tests show an inordinately long time to ignition that resulted in a prolonged period of white smoke prior to ignition. As a result, relatively high values of averaged SEA and relatively low values of averaged EHC obtained under these conditions were not indicative of flaming combustion expected in a room bum test. With earlier time to ignition, the higher heat flux levels resulted in an averaged EHC and peak SEA during flaming that was independent of flux levels. However, the averaged SEA increased with the heat flux levels mostly because of the smoke-point effect explained earlier.

The simplest correlation is to compare the predicted smoke-point RHR (taking the last column in Table 1 and dividing by the exposed specimen holder area of 0.00883 m^2) with the observed smoke-point RHR of the cone calorimeter. At the radiant fluxes of 50 kW/m^2, a few materials had flaming combustion always above the smoke-point, while most materials had

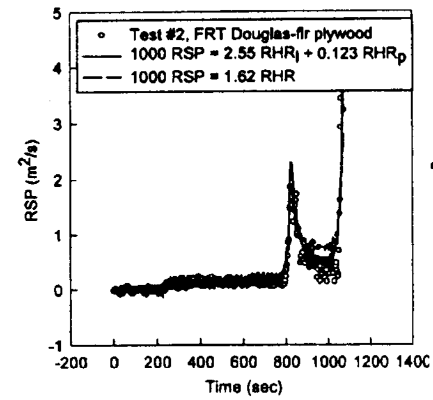

Figure 1 Correlation of RSP with RHR in Test #2

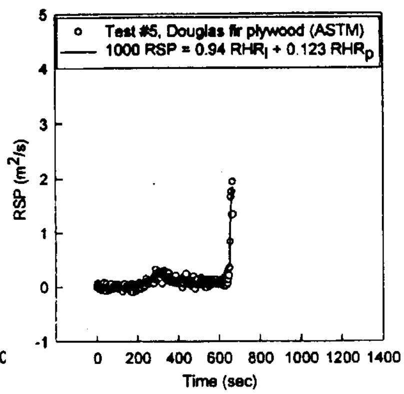

Figure 2 Correlation of RSP with RHR for Test #5

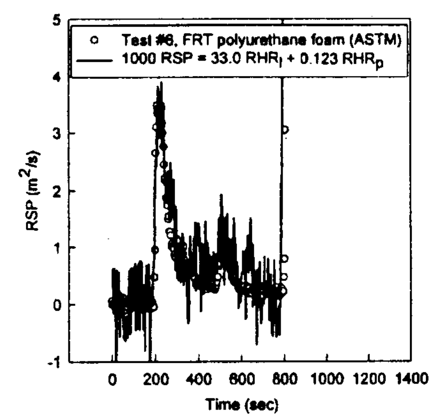

Figure 3 Correlation of RSP with RHR for Test #6

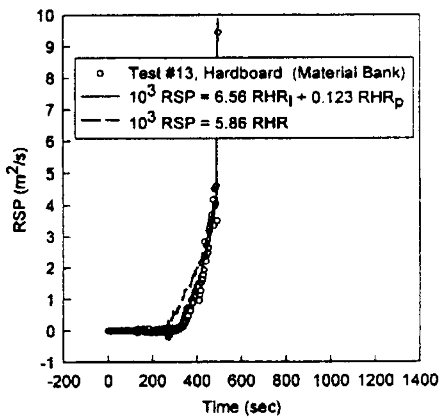

Figure 4 Correlation of RSP with RHR in Test #13

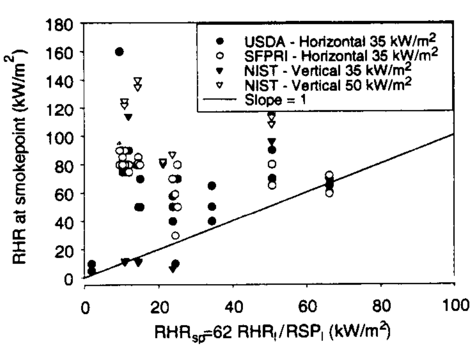

Figure 5 Smokepoint observed in the cone calorimeter compared to predicted smokepoint from room tests

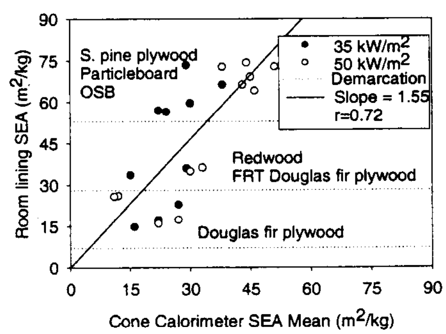

Figure 6. Correlation of lining SEA with SEA mean of cone calorimeter test of vertical specimen at 35 and 50 kW/m^2

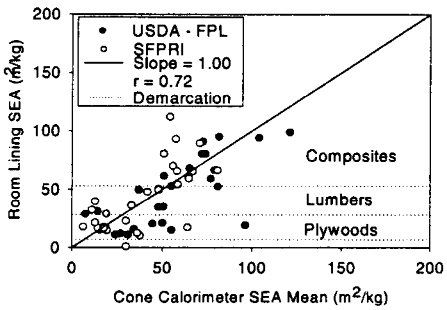

Figure 7 Correlation of lining SEA with SEA mean of cone calorimeter tests of horizontal specimen at 35 kW/m^2

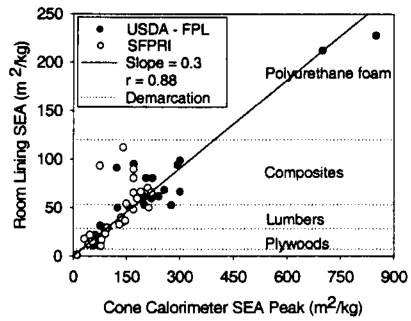

Figure 8 Prediction of lining SEA from SEA peak of cone calorimeter tests of horizontal specimen at 35 kW/m^2

flaming combustion always above the smoke- point at radiant fluxes of 65 kW/m^2. However, at the radiant flux of 35 kW/m^2, the smoke-point could be detected for nearly all materials by observing the rapid increase in SEA from some low value. Therefore, the result is shown in Figure 5 for four different types of cone calorimeter tests, which is explained as follows. For the materials in common between the tests in FPL and SFPRI cone calorimeters, the smoke-point RHR is essentially in agreement. The regression shows that the proportionality between predicted and observed smoke-point RHR has a correlation coefficient of zero. Even testing at heat fluxes of 35 and 50 kW/m^2 in the vertical orientation also indicate a zero correlation between observed and predicted smokepoint. This does not necessarily invalidate Delichatsios (1993) model but may mean increasing reliability of smoke-point observations by a test method modification. An example is using a small clean flame above the horizontal specimen to provide a stabllaminar flame sheet and optimum heat flux to the specimen.

Table 1 Smoke arameters derived rom re ression of E uation (8) to room RSP data

Material	Test #	a/EHC$_{cone}$ (m^2/MJ)	b/EHC$_{cone}$ (m^2/MJ*kW)	RSP$_1$ / RHR$_1$ (m^2/MJ)	RHR$_{smoke-point}$ (kW)
FRT Douglas-fir plywood	2	2.55	0.0	2.55	0.22
Oak veneer plywood	3	1.81	-	1.81	0.30
Douglas-fir plywood (ASTM)	5	0.94	-	0.94	0.58
FRT ol urethane foam	6	33.0	0.0	33.0	0.017
Gysum board - type X	7	0.288	0.0	0.288	1.9
FRT SYP plywood	8	2.93	0.0	2.93	0.19
Douglas-fir plywood (MB)	9	123	-	1.23	0.45
Southern pine plywood	10	5.20	-	520	0.11
Particleboard	11	5.67	-	5.67	0.097
Oriented strandboard (OSB) _	12	4.28	-	4.28	0.13
Hardboard	13	6.56	-	6.56	0.084
Redwood lumber	14	2.62	-	2.62	0.21
White spruce lumber	16	2.49	-	2.49	0.22
Southern ine boards	17	4.14	-	4.14	0.13
Waferboard	18	6.0I	-	6.01	0.091
Red oak	21	1.6	0.028	4.27	0.13
Stucco on OSB	22	2.35	0.0175	7.6	0.072

The next simplest correlation is to compare the lining SEA from Equation (9) with the averaged SEA from the cone calorimeter at different flux levels or surface orientation. Although it was observed that the EHC varies little with orientation or heat flux (within 10% error), the treated wood products have EHC about one-half that of untreated products. Therefore, through use of Equation (9) the treated products would be moved from the group of wood composites to a more reasonable level between plywood and lumber. This is easily seen in Figure 6 by comparing lining SEA to averaged SEA from cone calorimeter tests of vertical specimen at 35 and 50 kW/m^2. It is interesting that with a slope of 1.55 shown in Figure 6, the vertical orientation never provides a high enough SEA to match the level measured in the room test. The reason may be that the SEA does not approach a constant level at high fluxes in the vertical orientation. However, in the horizontal orientation, this leveling out of the SEA as RHR increases is almost always obtained in the cone calorimeter at heat fluxes above 30 kW/m^2. Perhaps the presence of propane flame impinging on the vertical linings in room tests is more suited to horizontal orientation in the cone calorimeter. It is also interesting that at fluxes of 50 and 65 kW/m^2 in the horizontal orientation, we now have a cone calorimeter SEA that is significantly higher than that of the lining SEA (not shown). We could argue that at these heat fluxes, the SEA is near the peak value most of the time, which may not be the situation in the room tests. Therefore, we then settled for a flux of 35 kW/m^2 in the horizontal orientation that provides a slope of unity with a correlation coefficient of 0.72 for predicting room lining SEA from the cone calorimeter SEA mean. This is shown in Figure 7 for plywood, lumber, and composites. The noise level is quite high in the horizontal, particularly for plywood, which may be due to unreliable processes of the smoke-point in the cone calorimeter.

The smoke parameter that may be more reliable than the smoke-point is the peak value of SEA during flaming. The vertical orientation is not practical because the SEA never leveled out at a maximum value after exceeding the smoke-point RHR. Once the radiant flux was above 30 kW/m^2 for the horizontal orientation, plywood and lumbers had a peak SEA that did not vary with heat flux. Some treated materials and composites did not, however, have a peak SEA that remained constant as the heat flux or RHR varied. By comparing different radiant fluxes, the correlation coefficient had the highest value ($r = 0.88$) for the radiant flux of 35 kW/m^2, as can be seen in Figure 8. If the hardboard is chosen as the outlying point. then the correlation coefficient would improve to 0.95 and the standard error would reduce to 16. The slope has a value of 0.3, which compared with Figure 7, seems to indicate that perhaps the room linings are below the smoke-point most of the time during burning.

CONCLUSION

Using the data from Dembsey et al. (1995) we determined that the mass outflow rate was 1.07 kg/s at an RHR of 1,000 kW in the ISO 9705 room. This translated to a global equivalence ratio of 0.33, which clearly indicates over-ventilation conditions in all phases of the room bum, even somewhat beyond the flashover conditions. Because of improved data acquisition and processing (Dietenberger et al. 1995) we were able to determine smoke contributions from the burner and room linings separately by synchronizing with the RHR of the burner and linings as a function of time. These factors obviated the need for a reference level of 400 kW proposed by Heskestad and Hovde (1999). Although the additivity relationship was successfully applied to smoke contributions, the problems of determining four phases of wood combustion, which are smoldering, flaming below the smoke-point, flaming above the smoke-point, and afterglow, made correlating the smoke at different scales difficult. Therefore, we considered (1) three different cone calorimeters (NIST, SFPRI, and FPL), (2) three different smoke parameters (RHR at smoke-point, averaged SEA, and peak SEA during flaming), (3) two specimen orientations (vertical and horizontal), and (4) at least four radiant flux levels (20, 35, 50, and 65 kW/m^2) as measured in the cone calorimeter. The best correlation to the lining smoke parameter, SEA, [as computed with Equation (9)] was found by multiplying by 0.3 the peak SEA during flaming of a horizontal specimen exposed to a radiant flux of 35 kWm^2. With much less reliability, the lining SEA is also equal to the averaged SEA for the same cone calorimeter condition. This optimum cone calorimeter condition is similar to that needed to match the specific RHR profile at both scales (Dietenberger and Grexa 1999). It is also equivalent to Mulholland et al. (1986) for using SEA from the matching of specific mass loss rate at both scales.

NOMENCLATURE

k	Extinction coefficient (1 /m)	Y_0	Oxygen mass fraction of air
$\dot{m}$	Fuel mass flow rate (MLR) (kg/s)	Δh_c	Heat of combustion (kJ/g)
$\dot{Q}$	Rate of heat release (RHR) (kW)	χ_s	Smoke yield per fuel mass
r_f	Oxygen/fuel mass stoichiometric ratio	ρ_s	Smoke mass density (kg/m^3)
S	Pure air/fuel mass stoichiometric ratio	σ_s	Specific extinction area(m^2/kg)
$\dot{V}$	Plume volumetric flow rate (m^3/s)		

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REFERENCES

Babrauskas, V. and Mulholland, G. 1987. Smoke and soot data determinations in the cone calorimeter. Mathematical Modeling of Fires, ASTM STP 983, p. 83-104. ASTM, West

Conshohocken, PA. Delichatsios, M.A. 1993. Smoke yields from turbulent buoyant jet flames. Fire Safety Journal 20:299-311.

Dembsey, N.A., Pagni, P.J., and Williamson. 1995. Compartment fire near-field entrainment measurements. Fire Safety Journal 24:383-419.

Dietenberger, M. 1999. Effect of Backing Board on the Heat Release Rate of Wood. In: Proceedings of the 28th International Conference on Fire Safety. Columbus, OH. 26-29 July, 1999. Sissonville, WV: Product Safety Corporation.

Dietenberger, M. and Grexa, O. 1999. Analytical model of flame spread in full-scale room/comer tests (ISO9705). In: Proceedings of the 6th Int. Conf. on Fire and Materials '99, February 1999, San Antonio, TX. p. 211-222.

Dietenberger, M.A., Grexa, O., White, R.H., Sweet, M., and Janssens, M. 1995. Room/comer tests of wall linings with 100/300 kW burner. In: Proceedings of the 4th Int. Conf. on Fire and Materials, Crystal City, VA, p. 53-62.

Grexa, O. 1996. Fundamental thermophysical properties of materials derived from the cone calorimeter measurements. In: Proceedings of the 3rd Int. Conf. of Wood & Fire Safety, The High Tatras, Slovakia, p. 139-149.

Janssens, M.J. 1991. Fundamental thermophysical characteristics of wood and their role in enclosure tire growth. Ph.D. Dissertation, University of Gent, Belgium.

Heskestad, A.W. and Hovde, P.J. 1999. Empirical prediction of smoke production in the ISO room comer fire test by use of ISO cone calorimeter fire test data. Fire and Materials 23: 193-199.

Mulholland, G.W. and Choi, M.Y. 1998. Measurement of the mass specific extinction coefficient for acetylene and ethane smoke using the large agglomerate optics facility. In: Proceedings of the 27th Int. Symp. on Combustion, Combustion Institute, Pittsburgh, PA, p. 1515-1522.

Mulholland, G.W., Henzel, V., and Babrauskas, V. 1986. Effect of scale on smoke emission. In: Proceedings of the 2nd Int. Symp. of Fire Safety Science, Int. Assoc. for Fire Safety Science, p. 347-357.

Ostman, B.A. and Tsantaridis, L.D. 1991. Smoke production in the cone calorimeter and the room fire test. Fire Safety Journal 17:27-43.

Ostman, B.A. and Tsantaridis, L.D. 1993. Smoke data from the cone calorimeter for comparison with the room fire test. Fire and Materials 17: 191-200.

Ou, S.S. and Seader, J.D. 1978. Smoke development from multiple materials. Journal of Fire & Flammability 9(Jan):30-49.

Quintiere, J.G. 1982. Smoke measurements: An assessment of correlations between laboratory and full-scale experiments. Fire and Materials 6(3 and 4): 145-160.

Tewarson, A. 1995. Generation of heat and chemical compounds in Fires. Section 3, Chapter 4. In: SFPE Handbook of Fire Protection Engineering, p. 3-53 to 3-124.

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