Quantification of Smoke Generated from Wood in the NBS Smoke Chamber

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ABSTRACT

The Aminco-NBS smoke density chamber (ASTM Method E 662) was used to study dynamic smoke generation from wood. Solid red oak and Douglas fir plywood were tested at three levels of heat flux under nonflaming exposure. Smoke particulate concentrations were obtained using a filtration method. Using linear regression analysis, a fairly simple family of equations was obtained to express the smoke generating properties of the two materials tested as functions of time and heat flux. Dry smoke particulate concentration correlated well with optical density. The derived equations constitute an empirical model to predict smoke generation properties of the species tested.

An evaluation of the suggested parameters, such as mass optical density (MOD), particulate optical density (POD) and particulate mass fraction (X), was carried out to determine their usefulness as predictive parameters. MOD and X are functions of time and flux, whereas POD should be a constant for a particular material.

Key words: NBS smoke chamber, smoke concentration, smoke optical density, woodsmoke.

INTRODUCTION

The NBS smoke density chamber has been traditionally used to evaluate the smoke generation properties of solid materials [1]. Results are

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expressed in terms of specific optical density ($D_s$) as a function of time and maximum value of $D_s$ ($D_m$) as well as time to reach $D_m$.

Transmission of light is obtained from the ratio of the incident ($I_o$) and transmitted ($I$) light intensities:

$$T\% = 100 \left( \frac{I}{I_o} \right)$$  \hspace{1cm} (1)

Optical density is defined as:

$$D = \log \left( \frac{I_o}{I} \right) = \log \left( \frac{100}{T\%} \right)$$  \hspace{1cm} (2)

Specific optical density is:

$$D_s = \frac{DV}{AL}$$  \hspace{1cm} (3)

where $V$ is the volume of the chamber; $A$ is the exposed surface of the specimen; $L$ is the length of the light path. Thus, $D$ and $D_s$ are dimensionless. For the NBS smoke chamber and the specified specimen size, $V/AL = 132$ or $D_s = 132D$.

Maximum specific optical density ($D_m$) is obtained when transmittance is at a minimum.

The results obtained from this standard test are single values based on a specific exposure condition (2.5 W/cm$^2$), under flaming or nonflaming mode. Because the chamber is a sealed box in which smoke is accumulated and only $D_m$ values are obtained for comparative purposes, it has been criticized for not being applicable to dynamic situations (varying flux levels and smoke flows).

Babrauskas [2] stated that the chamber can be used to predict full-scale fire flows if proper analysis is employed. In fact, many workers have modified the chamber and its calculations to derive predictive parameters for full-scale fires. A great deal of analysis of smoke accumulation in the NBS chamber was carried out at the University of Utah by Chien et al. [3], Seader and Chien [4-6], and Seader and Ou [7]. In the reports, the authors suggested two predictive parameters: mass optical density (MOD) and particulate optical density (POD). They are defined as follows:

$$\text{MOD} = D_sA/m \quad \text{where} \quad m = \text{mass loss of the specimen}$$  \hspace{1cm} (4)

$$\text{POD} = D_sA/m_p \quad \text{where} \quad m_p = \text{total mass of particulates}$$  \hspace{1cm} (5)

Both MOD and POD are expressed as cm$^2$/g.

In more recent studies, Brenden and LeVan [8,9] demonstrated the
relationship between MOD and POD by a parameter $X$ (particulate mass fraction).

$$X = \frac{\text{MOD}}{\text{POD}} = \frac{m_p}{m} = \frac{C_sV}{m}$$; $C_s = \text{particulate mass concentration}$

(6)

Note that $m$, $m_p$, $C_s$, and $D_s$ are all functions of time and flux, not to mention other variables such as species, moisture content, material density and thickness.

It is generally anticipated that $X$ may be a fundamental parameter, since it is related to the thermal decomposition and smoke forming mechanisms and could be a physical property of the material. The validity of this assumption has yet to be tested.

Babrauskas [2] showed that if particulate radius and density are uniform for a particular smoke, the particulate concentration ($C_s$) should be proportional to the extinction coefficient ($k$), which is proportional to the optical density ($D$) in the following relationship:

$$k = 2.303 \frac{D}{L}$$

(7)

One would expect that there can be some reasonable proportionality between the optical density ($D$) and the particulate concentration ($C_s$). Indeed, King [10] has found fairly linear relationships between optical density and mass density of smoke for some wood and plastic materials. The proportionality constants depend on the materials and whether flaming or nonflaming mode was used.

In this paper the objectives are:

1. Explore the smoke generating properties of selected wood materials with respect to time and different flux levels to develop an empirical model.
2. Investigate the relationship between $D_s$ and $C_s$, especially in the earlier stage of exposure, where coagulation and settling of smoke particulates are minimal.
3. Investigate the validity of MOD, POD and $X$ as physical properties of materials, using particulate concentration ($C_s$) and mass loss ($m$) data.

**EXPERIMENTAL**

**Materials**

Two materials were used: solid red oak and Douglas fir plywood (3 ply, 3/8 inch thick, marked A-C quality, suitable for exterior use). The
specimens from both materials were cut to the same size (3 in. by 3 in. square and 3/8 in. thick), and were conditioned at 73°F and 50% RH. The specimens were mounted so that their surface grain was horizontal.

**Equipment**

The photometer system was calibrated with Kodak Wratten filters of known optical densities. There was an exact linear relationship between transmittance and the recorded output signal. Thus, the output signal was recorded and then used to back calculate transmittance.

There was some question about the validity of the available radiometers as a result of aging and wear. We obtained new calibration values and were able to reconcile the two radiometers to within 0.05 W/cm². The uncertainty in radiant flux setting is estimated to be within 2%.

The analog output signal from the photometer was recorded on a stripchart recorder. Since we were only interested in the early stages of fire exposure, the recorder was set at one range (50 mV) and no range switching was carried out. The resolution was within 0.1 mV or 0.2% of full scale.

**Sampling and Analysis**

Smoke particulate concentration was obtained by filtration. The filtration technique was described in an earlier work at FPL [8,9]. Briefly, smoke was drawn into two evacuated 2-liter flasks through two 47-mm filter holders. Each filter holder contains two 47-mm Gelman A/E glass fiber filters in series (Figure 1). In previous studies carried out [8,9], it was assumed that the front filters removed particulates and some moisture. The back filters were assumed to absorb only moisture and their weight gains were used to correct for the front filters, assuming the filters gain the same amount of moisture.

Filter holders 1 and 2 were located at positions 432 and 222, respectively, according to the grid design described [8,9]. The chamber was divided into cubic cells 6 inches on each side. The numbering starts from the bottom front left corner. The three digits indicate the coordinate of the center of the selected cell. For example, location 432 means the cell is the fourth one to the right, third one to the back, and second one from the bottom. These two locations represent the average smoke concentrations in the chamber as cited in above references. Temperatures at the sampling positions were continuously monitored.

A number of preliminary runs were conducted to determine the vari-
ability of moisture absorbed on the front and back filters. It was found that the moisture collected on the front filter was much greater than that of the back filter. Therefore, a new weighing procedure was devised to improve smoke particulate concentration measurement.

The filters were labeled 1A, 1B, 2A and 2B, corresponding to the front and back filters in filter holders 1 and 2, respectively. The filters were weighed to the nearest 0.1 mg using a Chainomatic balance. The weighing sequence is described below:

1. Tare weights of the filters, dried over $\text{P}_2\text{O}_5$ under vacuum for 24 hours
2. Weights of used filters, right after sampling
3. Weights of used filters, dried over $\text{P}_2\text{O}_5$ in vacuo for 24 hours, after weighing in step 2

The difference between 1 and 2 is the wet weight of the smoke particulates; the difference between 1 and 3 is the dry weight of the smoke particulates; and the difference between 2 and 3 is the moisture collected.

The used filters obtained from a preliminary run, both before and
after desiccation, were extracted with chloroform and analyzed by GC-MS. No volatile compound was detected. This validated the assumption that the differences as a result of drying are indeed due to moisture alone.

For each material, three flux levels were used: 2.0, 2.5, 3.0 W/cm², under nonflaming mode. For each flux level, runs of different durations were carried out in triplicate. The time durations selected were arbitrarily selected as 4, 8, 10, 12, and 14 minutes.

Triplicate runs were carried out in all cases except for red oak at 2.0 and 3.0 W/cm² and 4-minute duration, where only two replicates were made. The reason was that smoke weights were very small and good agreement was obtained in two replicates. Therefore, the total number of runs was 88 instead of 90.

In addition, six runs were conducted for the two materials at three flux levels, without drawing smoke samples into the evacuated flasks to observe any significant deposition of smoke on the filters during the tests. The time duration for all of these tests was 14 minutes.

The specimen plus the specimen holder was weighed before and after the tests to determine weight loss by difference.

**Correction for Smoke Sample Volume**

When the smoke samples were drawn into the respective flasks, there was a drop in temperature due to both the sudden expansion and thermal loss to the outside. The volumes of the flasks have to be corrected estimate smoke sample volumes. The more significant change that must be taken into account is temperature. It was found [9] that the temperature in the flasks just after sampling obeyed the empirically determined equation:

\[
T_s = T_r - 0.77 \left( T_s - T_r \right)
\]

where \( T_s \) = temperature of the flask, \( T_r \) = temperature at the sample holder, \( T_r \) = room temperature. Assuming the ideal gas law and constant pressure, the volumes of the flasks were multiplied by a factor of \( T/T_s \) to obtain the corrected smoke sample volumes. The original volumes of the flasks were 2208 and 2231 cm³, corresponding to samples 1 and 2, respectively. The volume correction is normally less than 5%.

Since the sample volumes are very small compared to the chamber volume (less than 1%), changes in chamber pressure as a result of sampling are insignificant. Atmospheric pressure varied from day to day.
However, the variability was small and the chamber pressure was assumed to be constant. No correction for pressure was made.

**Correction for Deposition of Smoke Particulates**

We observed deposition of smoke particulates on the windows of the light extinction system, causing a reduction in transmittance of light after the termination of the test, and after complete evacuation of smoke. By cleaning the glass windows with ethanol, transmittance can be restored to the original 100%. The standard ASTM E 662 test suggests the use of the difference in transmittance due to deposition on the glass windows to correct for $D_m$ since the deposition of smoke caused an error in the smoke optical density value. In this study, we were not interested in $D_m$, but rather in the earlier stages of smoke development. In most cases, the correction is rather insignificant with respect to $D$. Therefore, the correction to $D$ due to deposition of smoke was ignored.

Since deposition of smoke occurred on the glass windows, deposition occurred on the walls and the glass filters as well. To account for the amount of smoke particulates deposited on the filters, a series of runs were carried out in the same manner as designed, except that no vacuum was drawn and no sample taken. The six runs include three flux levels for the two species and 14-minute durations. We found in most cases that the amount of smoke deposited on the filters was either zero or insignificant. There was no apparent correlation between reduction in transmittance due to deposition on the glass windows and the deposition on the filters. One possible explanation is that the glass windows are horizontal and the filters are oriented vertically. The vertical filters are less susceptible to the settling of smoke. Due to the insignificant amount of smoke deposition on the filters, the effect of particulate deposition on smoke particulate concentration is ignored.

**RESULTS AND DISCUSSION**

**Variability in Specimens**

The original weights of the conditioned specimens used in this study are described in Table 1. The average moisture contents of the red oak and Douglas fir plywood specimens are 6.8% and 7.4%, respectively. The coefficient of variation of Douglas fir plywood weight is much higher than that of red oak. Since the two types of specimens have the same dimension (3 by 3 by 3/8 in.) and volume (55.35 cm³), the red oak specimens were 1.4 times denser than the Douglas fir samples. The
specific gravities of red oak and Douglas fir plywood were 0.70 and 0.49, respectively.

**Weight Loss**

Specimen weight loss is calculated as a percentage of original specimen weight and plotted in Figures 2 and 3 for red oak and Douglas fir plywood, respectively. In these figures, each point represents the average of the three replicate runs. The maximum and minimum numbers are included to indicate variability between runs. The family of curves are fairly continuous in case of red oak (Figure 2). For Douglas fir plywood, however, the curves are less smooth (Figure 3). The lack of continuity of weight loss of Douglas fir plywood may be due to the ply structure, where the middle layer has grain direction perpendicular to the two outside layers. Evidently, specimen weight loss is a function of time and flux.

![Figure 2. Weight loss (%) by time, red oak (ML87 5424)](image)
As discussed earlier, the dry smoke weights obtained after desiccation of the smoke filters were used because they are the actual weights of particulates. The amount of moisture absorbed by the filters depends on external factors such as relative humidity of the environment and should be eliminated from the analysis. Therefore, smoke particulate concentration mentioned hereafter will be based on the dry smoke weights.

The sums of smoke weights in each filter holder represent smoke particulate weights. These values divided by the corrected sample volumes give us smoke concentrations in g/m$^3$. Average smoke particulate concentration is taken from sample holders 1 and 2 for each run, and plotted in Figures 4 and 5 for red oak and Douglas fir plywood, respectively. The maximum and minimum values for the triplicate runs indicate variability between runs.

Similar to weight loss data, red oak shows continuous behavior in smoke particulate concentrations, whereas Douglas fir plywood has less continuity, especially at flux level of 3.0 W/cm$^2$. This lack of smoothness is possibly due to the ply structure of plywood. Again, the family of curves for each species suggests that smoke particulate concentration is a function of time and flux.
Empirical Correlations

SMOKE PARTICULATE CONCENTRATION VERSUS TIME AND FLUX

Smoke particulate concentrations are related to time and flux using linear regression analysis. There are a few formulas that adequately fit the data. The two best fits are the quadratic and the exponential forms.
The exponential form was preferred for its simplicity. A multiplicative model was chosen to force $C_s$ through zero when time or flux is zero. The exponential equations have the following forms:

For a given material and a given flux level:

$$C_s = 10^a \cdot t^b$$  \hspace{1cm} (9)

For a given material:

$$C_s = 10^a \cdot t^b \cdot i^c$$  \hspace{1cm} (10)

where $a$, $b$, $c$ are dimensionless coefficients, $C_s$ is in g/m$^3$, $t$ is in minutes and $i$ is radiant flux in W/cm$^2$.

The coefficients and their standard errors obtained by regression analysis for Equations (9) and (10) are tabulated in Tables 2 and 3, respectively.

These equations are valid for the nonflaming condition in the range of flux investigated (2.0 W/cm$^2$ to 3.0 W/cm$^2$), specimen size mentioned and within 14 minutes of exposure. Extrapolation beyond the experimented ranges should be exercised with care.

**SPECIFIC OPTICAL DENSITY ($D_s$) COMPARED TO SMOKE PARTICULATE CONCENTRATION ($C_s$)**

Using linear regression analysis, we found $D_s$ is proportional to $C_s$ for both materials tested. The linear regression results are summarized in Table 4. The scatter of data around the regression lines for red oak and Douglas fir plywood is shown in Figures 6 and 7, respectively. The dotted lines represent 95% confidence intervals.

There are no significant differences between the two species statistically, and the two equations can be combined to give:

$$D_s = 167.4 \cdot C_s$$  \hspace{1cm} (11)

**MASS OPTICAL DENSITY (MOD)**

By definition, MOD = $D_s \cdot A/m$ (in cm$^2$/g). $A$ is a constant (40.31 cm$^2$ of exposed specimen area), $D_s$ and $m$ are both functions of time and flux. It is expected that MOD is a function of time and flux. The empirical expression of $D_s$ with respect to time and flux can be obtained directly using linear regression analysis. Results are shown in Table 5.

Using the same exponential model, a fairly good fit was found for the relationship between $m/A$ and time and flux. The coefficients obtained by linear regression analysis are given in Table 6.
Table 2. Coefficients for equation \( C_s = 10^a \cdot t^b \).

<table>
<thead>
<tr>
<th>Species</th>
<th>Flux (W/cm²)</th>
<th>a/s.e.</th>
<th>b/s.e.</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red oak</td>
<td>2.0</td>
<td>-2.255/0.144</td>
<td>1.90910.146</td>
<td>0.934</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>-2.254/0.108</td>
<td>2.54110.112</td>
<td>0.975</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>-0.979/0.071</td>
<td>1.58110.072</td>
<td>0.976</td>
</tr>
<tr>
<td>Douglas fir plywood</td>
<td>2.0</td>
<td>-1.228/0.111</td>
<td>1.20510.116</td>
<td>0.893</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>-1.486/0.084</td>
<td>1.83710.087</td>
<td>0.972</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>-0.351/0.086</td>
<td>0.922/0.089</td>
<td>0.892</td>
</tr>
</tbody>
</table>

s.e.: standard error of coefficient

Table 3. Coefficients for equation \( C_s = 10^a \cdot t^b \cdot f \).

<table>
<thead>
<tr>
<th>Species</th>
<th>a/s.e.</th>
<th>b/s.e.</th>
<th>c/s.e.</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red oak</td>
<td>-4.017/0.133</td>
<td>2.046/0.096</td>
<td>5.482/0.241</td>
<td>0.960</td>
</tr>
<tr>
<td>Douglas fir plywood</td>
<td>-2.378/0.114</td>
<td>1.322/0.080</td>
<td>3.459/0.212</td>
<td>0.927</td>
</tr>
</tbody>
</table>

s.e.: standard error of coefficient.

Table 4. Coefficient for equation \( D_s = a \cdot C_s \).

<table>
<thead>
<tr>
<th>Species</th>
<th>a/s.e.</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red oak</td>
<td>178.9/5.955</td>
<td>0.976</td>
</tr>
<tr>
<td>Douglas fir plywood</td>
<td>161.2/7.507</td>
<td>0.954</td>
</tr>
<tr>
<td>Overall</td>
<td>167.4/5.056</td>
<td>0.961</td>
</tr>
</tbody>
</table>

s.e.: standard error of coefficient

Table 5. Coefficients for equation \( D_s = 10^a \cdot t^b \cdot f \).

<table>
<thead>
<tr>
<th>Species</th>
<th>a/s.e.</th>
<th>b/s.e.</th>
<th>c/s.e.</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red oak</td>
<td>-3.048/0.200</td>
<td>2.747/0.108</td>
<td>7.238/0.366</td>
<td>0.971</td>
</tr>
<tr>
<td>Douglas fir plywood</td>
<td>-1.808/0.229</td>
<td>2.318/0.125</td>
<td>5.456/0.440</td>
<td>0.946</td>
</tr>
</tbody>
</table>

s.e.: standard error of coefficient

Table 6. Coefficients for equation \( m/A = 10^a \cdot t^b \cdot f \).

<table>
<thead>
<tr>
<th>Species</th>
<th>a/s.e.</th>
<th>b/s.e.</th>
<th>c/s.e.</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red oak</td>
<td>-3.336/0.055</td>
<td>1.534/0.039</td>
<td>2.938/0.099</td>
<td>0.984</td>
</tr>
<tr>
<td>Douglas fir plywood</td>
<td>-3.061/0.060</td>
<td>1.313/0.042</td>
<td>2.573/0.112</td>
<td>0.973</td>
</tr>
</tbody>
</table>

s.e.: standard error of coefficient
Figure 6. Smoke particulate concentration by specific optical density, red oak (ML87 5428).

Figure 7. Smoke particulate concentration by specific optical density, Douglas fir plywood (ML87 5429).
By combining the equations obtained by correlation of $D_s$ with time and flux in Table 5 with the equations for $A/m$ obtained in Table 6, we obtained the equations for MOD (Table 7).

It is observed that the coefficient $b$ is almost unity, indicating that MOD is proportional to time. However, there is a stronger dependence of MOD on flux and species. For red oak, MOD is proportional to a power of 4.3 of flux; for Douglas fir plywood, the power is about 2.8.

**PARTICULATE (OPTICAL DENSITY (POD))**

By definition, $POD = D_s \cdot A/m_p$. $A$ is a constant, $D_s$ is proportional to $C_s$, $m_p$ is proportional to $C_s$. Therefore, POD is expected to be constant for each species. Particulate optical densities of red oak and Douglas fir plywood can be calculated as follows:

Red oak:

$$POD = D_s \cdot A/m_p = 178.9 \cdot C_s \cdot A/C_s \cdot V = 178.9 \cdot A/V = 14,140 \, \text{cm}^2/\text{g}$$

Douglas fir:

$$POD = 161.2 \cdot C_s \cdot A/C, \cdot V = 161.2 \cdot A/V = 12,740 \, \text{cm}^2/\text{g}$$

If an average proportional constant of 167.4 is assumed for both species, then POD for both red oak and Douglas fir plywood is 13,230 cm$^2$/g. Particulate optical density of 13,230 cm$^2$/g is lower than the previously reported values of around 20,000 by Brenden [8]. The main difference is due to the fact that $C_s$ is based on dried smoke weights which are significantly lower than those of wet smoke.

**MASS FRACTION OF PARTICULATES ($X$)**

By definition $X = MOD/POD = m_p/m$. $X$ is the fraction of the mass loss that is converted to smoke particulates. $X$ is a function of time and flux. The average $X$ values for the triplicate runs are summarized in Table 8 and plotted in Figures 8 and 9 for red oak and Douglas fir ply-

<table>
<thead>
<tr>
<th>Species</th>
<th>a</th>
<th>b</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red oak</td>
<td>288</td>
<td>1.213</td>
<td>4.300</td>
</tr>
<tr>
<td>Douglas fir plywood</td>
<td>1.253</td>
<td>1.006</td>
<td>2.883</td>
</tr>
</tbody>
</table>
Table 8. Particulate mass fraction ($X$).

<table>
<thead>
<tr>
<th>Species</th>
<th>Time (min)</th>
<th>Flux (W/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Red oak</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.00</td>
<td>0.038</td>
<td>0.050</td>
</tr>
<tr>
<td>8.00</td>
<td>0.035</td>
<td>0.088</td>
</tr>
<tr>
<td>10.00</td>
<td>0.044</td>
<td>0.104</td>
</tr>
<tr>
<td>12.00</td>
<td>0.050</td>
<td>0.132</td>
</tr>
<tr>
<td>14.00</td>
<td>0.062</td>
<td>0.133</td>
</tr>
<tr>
<td>Douglas fir plywood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.00</td>
<td>0.155</td>
<td>0.100</td>
</tr>
<tr>
<td>8.00</td>
<td>0.108</td>
<td>0.145</td>
</tr>
<tr>
<td>10.00</td>
<td>0.100</td>
<td>0.161</td>
</tr>
<tr>
<td>12.00</td>
<td>0.111</td>
<td>0.130</td>
</tr>
<tr>
<td>14.00</td>
<td>0.120</td>
<td>0.174</td>
</tr>
</tbody>
</table>

Red oak, respectively. There is a general upward trend in $X$ with respect to flux and time for red oak. This trend is less visible in Douglas fir plywood. It is evident that $X$ depends strongly on species and flux. The relationship between $X$ and the variables are too complex to be useful. Again, for the limited number of species and conditions tested, there was not sufficient data to make any prediction based on $X$.

Figure 8. Mean particulate mass fraction by time, red oak (ML87 5430).
CONCLUSIONS

Based on the experimental design, it was demonstrated that dynamic smoke generation properties of solids can be obtained from the NBS smoke density chamber. For each particular material, many runs had to be conducted to obtain the relationship of smoke particulate concentration with time and flux. In this particular case, 45 runs were carried out for each material (3 flux levels, 5 durations, and 3 replicates). Smoke particulate concentrations based on filtration and desiccation procedures correlated well with optical densities.

The relationship of smoke particulate density (MOD) with respect to time and flux can be obtained for each species using forms as suggested earlier. These functions can be useful in predicting smoke growth and accumulation.

Based on the limited data base obtained, the behaviors of MOD and POD as well as their ratio (X) seem to have limited application in modeling wood materials. POD is more or less constant, whereas MOD and X vary with time and flux and their interrelationships are not clear.

The number of runs can be reduced if continuous monitoring of smoke particulate concentrations and specimen weight loss can be carried out. Weight loss measurement can be implemented fairly...
readily, but a system to monitor smoke particulate concentration on a continuous basis is yet to be devised. Thus, numerous runs of different durations are still needed to obtain the smoke particulate concentration data needed by filtration.

There are a great number of variables that have not yet been explored: the effect of species, specimen thickness, moisture content, density, higher flux levels, arid exposure mode (flaming and nonflaming). This study has suggested a feasible method to derive the dynamic smoke generation data using the NBS chamber.

ACKNOWLEDGEMENT

The author is grateful to Pam Plantinga, statistician at the Forest Products Laboratory, for assistance in the statistical analysis of the data. Also, special thanks to John J. Brenden for assistance in the planning of this study.

NOMENCLATURE

\[ I_o = \text{Intensity of light source} \]
\[ I = \text{Intensity over given path length} \]
\[ D = \text{Optical density} \]
\[ D_s = \text{Specific optical density} \]
\[ V = \text{Chamber volume, m}^3 \]
\[ C_s = \text{Particulate concentration of smoke (dry basis), g/m}^3 \]
\[ T = \text{Temperature, kelvins} \]
\[ T\% = \text{Percent transmittance} \]
\[ A = \text{Exposed area of specimen, cm}^2 \text{ or m}^2 \text{ when specified} \]
\[ m = \text{mass loss of specimen, g} \]
\[ m_p = \text{total particulate mass (dry basis), g} \]
\[ \text{MOD} = \text{Mass optical density, cm}^2/g \]
\[ \text{POD} = \text{Particulate optical density, cm}^2/g \]
\[ X = \text{Mass fraction of particulates} \]
\[ t = \text{time, duration of run, minutes} \]
\[ l = \text{heat flux level, w/cm}^2 \]
\[ L = \text{light path, m} \]

REFERENCES


