User's Guide for Fire Calorimetry Database (FCD)

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1) Overview the Fire Calorimetry Database (FCD)

The Fire Calorimetry Database (FCD) contains compilation of fire experiments conducted at the NIST National Fire Research Laboratory (NFRL). The FCD contains a summary data page for each fire experiment. The basic test information is given in Table 1. If available, a time compressed video of the fire with heat release rate data overlay is provided. The time series data collected during the test is provided in comma separated values (.csv) files at 1 second time intervals. Table 2 of the experiment data page shows a summary of test measurement results. Table 3 provides a summary of input parameters used in the calorimetry calculations. Time series plots of the heat release rate and combustion products species are shown for each test and include markers for annotated events during the test. A snapshot image from the test video is provided for each event. Each test has a minimum of two events for "ignition" and "fire out". The database is organized into projects and can searched by keywords or sorted by selected fields such as fuel type or total heat release.

2) Guide for referencing the FCD data

There are multiple citations for experiments contained in this database. Each project has at least one report or journal article that describes the test methods, results and conclusions of the study. This reference should be cited when referring to experiments from a single project. The NIST Technical Note 2077 [1] should be cited when referencing the calorimetry methods or uncertainty analysis in this database. Finally, the NIST Fire Calorimetry Database [2] should be cited when using video, images, or data files or summary calculations found here.

3) Description of FCD calculations

The generation rates of energy and combustion products are calculated over the time period from ignition (t_{ign}) to fire out (t_{out}). These two events are marked electronically in the data file and are required in order to generate the standard report. The total amount of heat generated by the fire is:

$$\text{Total Heat Release (THR)} = \sum_{t=t_{\text{ign}}}^{t_{\text{out}}} \dot{Q}_{oc}(t)\,\Delta t$$

where $\dot{Q}_{oc}(t)$ is the heat release rate (HRR) determined by oxygen consumption calorimetry at time t and defined by Equation 2 in TN2077 [1]. The total amounts of product species and the total amount of oxygen consumed are given by:

$$\text{Total CO}_2 = \frac{\text{M}_{\text{CO}_2}}{\text{M}_{\text{air}}} \sum_{t=t_{\text{ign}}}^{t_{\text{out}}} \left[X_{\text{CO}_2}(t) - X^{\text{o}}_{\text{CO}_2}\right] \dot{m}_{\text{e}}\,\Delta t$$

$$\text{Total CO} = \frac{\mathrm{M_{CO}}}{\mathrm{M_{air}}} \sum_{t=t_{\mathrm{ign}}}^{t_{\mathrm{out}}} [X_{\mathrm{CO}}(t) - X_{CO}^{\mathrm{o}}]\, \dot{m}_{\mathrm{e}}\, \Delta t$$

$$\text{Total } \mathrm{O_2} = \frac{\mathrm{M_{O_2}}}{\mathrm{M_{air}}} \sum_{t=t_{\mathrm{ign}}}^{t_{\mathrm{out}}} \left[X_{\mathrm{O_2}}^{\mathrm{o}} - X_{\mathrm{O_2}}(t)\right] \dot{m}_{\mathrm{e}}\, \Delta t$$

where

$\dot{m}_{\mathrm{e}}$ = mass flow rate in exhaust duct, kg/s

M_i = molecular weight of gas i, kg/kmole

X_i = volume fraction of exhaust gas i, L/L

X_i^{o} = volume fraction of ambient gas i, L/L

The mass of fuel consumed by the fire, Δm_{fuel}, can be estimated by two different methods: (1) a load cell measures the mass of the specimen before, $m_{\mathrm{fuel,i}}$, and after, $m_{\mathrm{fuel,f}}$, the test; or (2) the measured total heat release (THR) is divided by an assumed (i.e. literature value) fuel heat of combustion. If both fuel consumption measurements are available, the value used to calculate species yields is the one with lower uncertainty. If the load cell measurement of fuel mass loss is available, the heat of combustion can be estimated as follows:

$$\text{Net Effective Heat of Combustion} = \mathrm{HOC_{fuel,eff}} = \frac{\mathrm{THR}}{\Delta m_{\mathrm{fuel}}}$$

The species yields are given by the following expressions:

$$\mathrm{CO_2}\ \text{Yield} = \mathrm{y_{CO_2}} = \frac{\text{Total } \mathrm{CO_2}}{\Delta m_{\mathrm{fuel}}}$$

$$\text{CO Yield} = \mathrm{y_{CO}} = \frac{\text{Total CO}}{\Delta m_{\mathrm{fuel}}}$$

$$\mathrm{O_2}\ \text{Yield} = \mathrm{y_{O_2}} = \frac{\text{Total } \mathrm{O_2}}{\Delta m_{\mathrm{fuel}}}$$

The smoke particulate generated by the fire is measured via the light extinction of a HeNe laser beam across the center of the exhaust duct. The measurement method is described by Mulholland et al [3]. The intensity of the signal of the Si photodiode detector at time t is given by $I(t)$. The background intensity, I^{o}, is the mean intensity over a 60 s period before ignition. The light extinction coefficient, K, is defined:

$$K(t) = \frac{1}{D_{\mathrm{eff}}} \ln \frac{I^{\mathrm{o}}}{I(t)}$$

where D_{eff} is the effective duct diameter. The total amount of particulate (i.e. soot) matter generated by the fire is:

$$\text{Total Soot} = \frac{A}{\sigma_{\mathrm{s}}} \sum_{t=t_{\mathrm{ign}}}^{t_{\mathrm{out}}} K(t)\, V_{eff}(t)\, \Delta t$$

where A is the cross sectional area of the duct, $V_{eff}(t)$ is the effective velocity of the effluent, and σ_{s} is the specific extinction coefficient, which is assumed to be 8700 $\mathrm{m^2/kg}$ unless otherwise specified. The soot yield of the fire, averaged over the entire burn, is:

$$\text{Soot Yield} = \ y_{\mathrm{soot}} = \frac{\text{Total Soot}}{\Delta m_{\mathrm{fuel}}}$$

The uncertainty values given in Table 2 are based on a propagation of uncertainty from the input parameters in Table 3 and uncertainty estimates determined as described in TN 2077. Figure 15 of TN 2077 provides the results of a linear regression of the data for expanded relative uncertainty of the heat release rate measurement. Uncertainty estimates are computed using empirical formulas such as the one below ($\dot{Q}_{OC}$ = [MW]), an example case of the 3 MW hood with a generic combustible fuel.

$$\frac{U_{\dot{Q}_{OC}}(t)}{\dot{Q}_{OC}(t)} = 0.0683\ \dot{Q}_{OC}(t)^{-0.028}$$

Estimates of uncertainty of the burner heat release rate are computed from the results of the linear regression provided in Figure 18 of TN 2077.

Total heat released is a summation of measurements made by the same instrument, therefore each measurement, $\dot{Q}_{OC}(t)$, is correlated. The uncertainty of a summation of correlated measurements is the summation of the uncertainties, whenever the correlation coefficient is unity, r(i,j) = 1.0. Therefore, the uncertainty of the total heat release is given as:

$$U_{\mathrm{THR}} = \sum_{t=t_{\mathrm{ign}}}^{t_{\mathrm{out}}} U_{\dot{Q}_{OC}}(t)\, \Delta t$$

The standard deviation of each of the measurement components was calculated for the background measurement period of 60 s during ambient air conditions before the fire was ignited. If the measured values were less than 10 times the background standard deviation the background standard deviation was added to the uncertainty to provide a conservative estimate. This is necessary because the regression analysis in Figure 15 does not include low values of heat release. The same method is applied to the calculation of combustion species yields.

Not all measurements are performed for each test. Missing values are shown as “Not measured” in the summary of test results table. If the measurement value in table 2 is less than 3 times the standard measurement uncertainty the value is displays as “below detection limit”.

References

[1] Bryant, R. and Bundy, M. The NIST 20 MW Calorimetry Measurement System for Large-Fire Research, Technical Note (NIST TN) 2077, 2019 https://doi.org/10.6028/NIST.TN.2077

[2] NIST Fire Calorimetry Database https://doi.org/10.18434/mds2-2314

[3] Mulholland, G, Johnsson, E, Fernandez, M, Shear, D (2000) Design and Testing of a New Smoke Concentration. *Fire and Materials*. 24, 231-243