Cone Calorimetry

Mark McKinnon

Lab Test Methods Day 2014

Background

Cone Calorimetry

- Well–defined heat flux incident to one face of a flat sample with a truncated cone–shaped heater.
- Employs the principle of Oxygen Consumption Calorimetry.
- Mass Measured as the material burns.

Data Collected:

Mass of sample, composition of combustion products, time to ignition, extinction coefficient of smoke

Properties/Parameters Determined from Data:

Heat release rate, Burning rate, Effective heat of combustion, Thermal response parameter, Yields of combustion byproducts.

Governing Principles

Background

Governing Principles

Operational Procedure

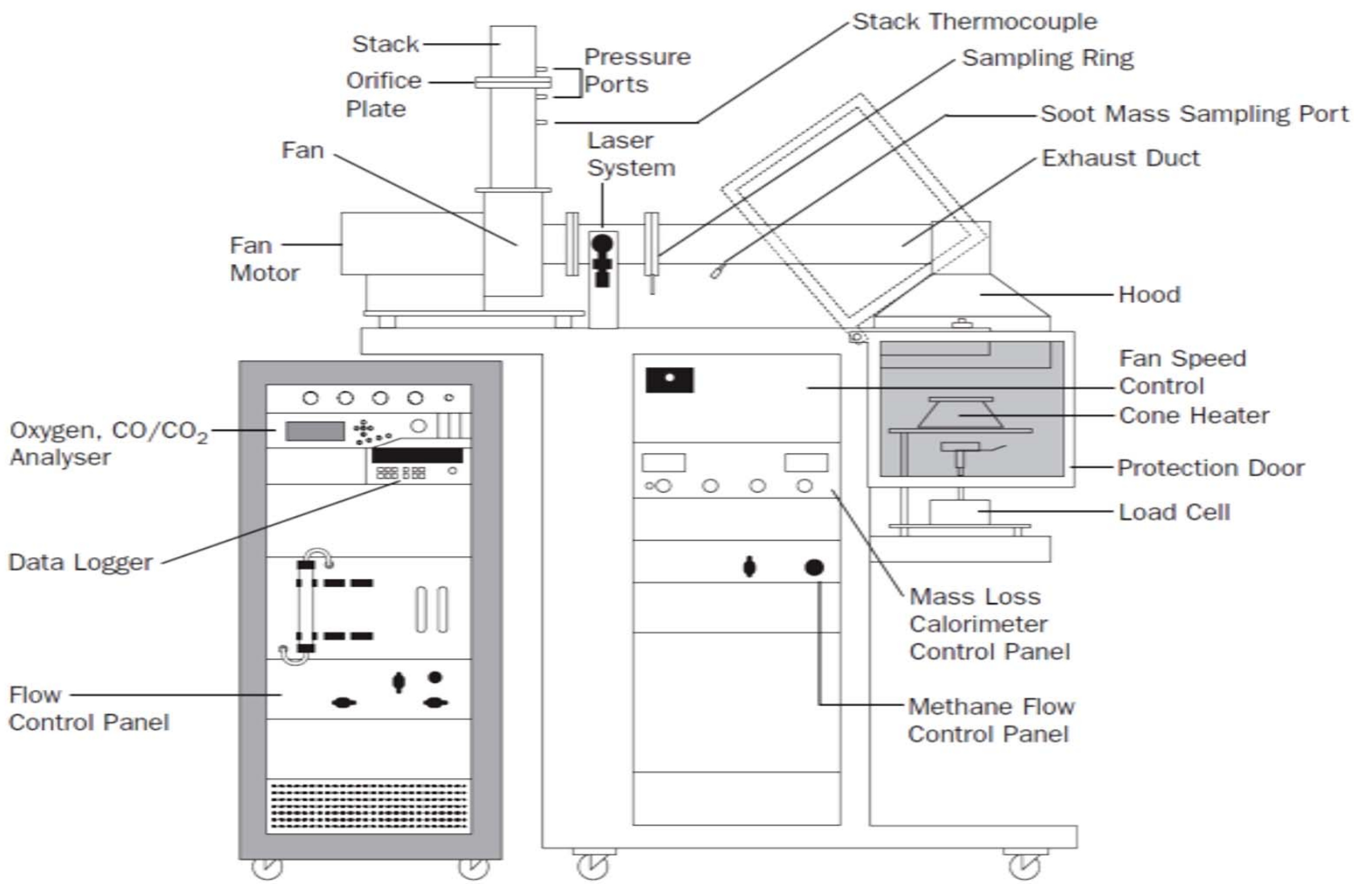
Data Analysis

Limitations

Sensitivity Analysis

Tips for Operation

Additional Information



Governing Principles

Background

Governing Principles

Operational Procedure

Data Analysis

Limitations

Sensitivity Analysis

Tips for Operation

Additional Information

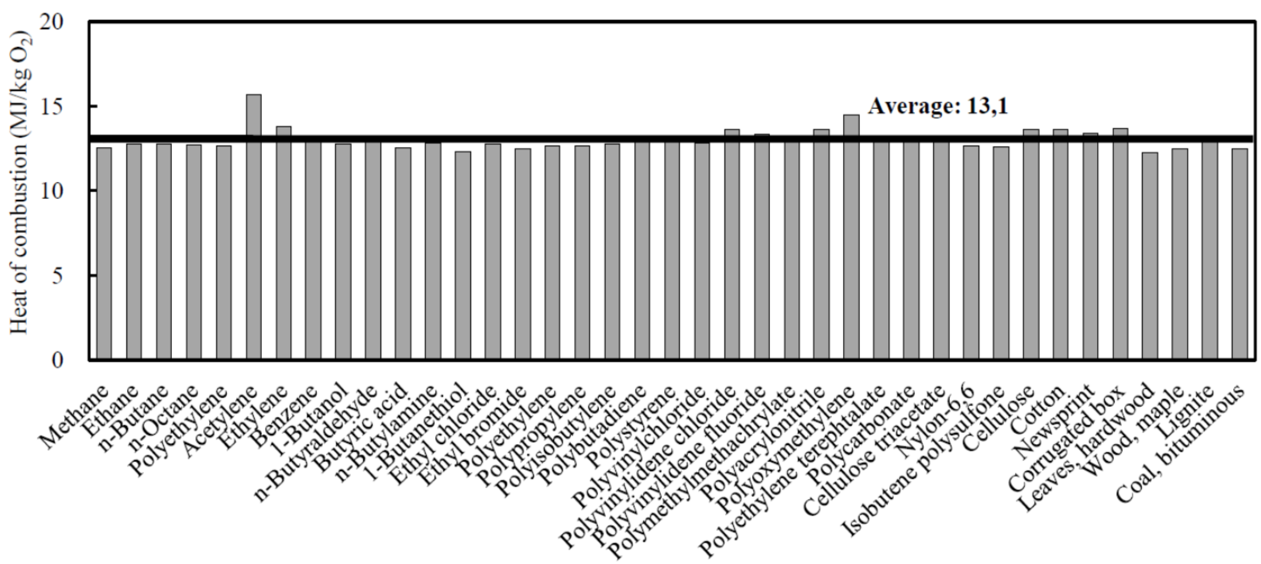
Determine C–Factor based on a well–defined methane flame

$$C = \frac{5.0}{1.10(12.54 \times 10^3)} \sqrt{\frac{T_e}{\Delta P} \frac{1.105 - 1.5X_{O_2}}{{X_{O_2}}^0 - X_{O_2}}}$$

The heat release rate relative to the heat release rate of methane is determined based on the oxygen concentration in the combustion products:

$$\dot{Q}(t) = \left(\frac{\Delta h_c}{r_o}\right)(1.10)C\sqrt{\frac{\Delta P}{T_e}} \frac{\left({X_{O_2}}^0 - X_{O_2}(t)\right)}{1.105 - 1.5X_{O_2}(t)}$$

$$\frac{\Delta h_c}{r_o} = 13.1 \times 10^3 \text{ kJ/kg } O_2$$



Governing Principles

The effective heat of combustion is calculated based on the summation of the heat release rate and the change in mass from the beginning to the end of the test:

$$\Delta h_c = \frac{\sum_i \dot{q}_i\,(t)\Delta t}{m_i - m_f}$$

The extinction coefficient, *k*, of the combustion products (smoke) is calculated by measuring the attenuation of intensity of a laser projected through the combustion products. The Beer–Lambert law is used to calculate the extinction coefficient:

$$k = \left(\frac{1}{L}\right)\ln\frac{I_o}{I}$$

Operational Procedure

Calibration:

1. Zero the difference between the pressure transducers in the stack
2. Zero and calibrate the gas analyzer, watching for the oxygen level to achieve 20.95% when ambient air is tested.
3. Calibrate the heat release rate measurement against a standard size methane flame (5 kW)
4. Zero and calibrate the weighing system with a standard mass.
5. Verify the zero point of the extinction coefficient.
6. Set the temperature of the heater such that the heat flux incident to a heat flux gauge at a distance from the heater equivalent to the distance from the heater to the sample surface is at the desired set point.

Operational Procedure

Testing:

1. Insert the radiation shield and position the sample specimen.
2. Position the spark igniter above the sample surface
3. Remove the radiation shield and begin collecting data
4. Record the time until the flame exists over most of the sample surface for at least 4 seconds
5. Continue with the test until 2 minutes after any of the following occur:
   1. Flaming and other signs of combustion cease
   2. The average mass loss over a 1 minute period drops below 150 g/m^2
   3. The specimen mass returns to the pre–test value
   4. The heat release rate drops below 5 kW/m^2 for 10 minutes
   5. 60 minutes has elapsed

Data Analysis

Background

Governing Principles

Operational Procedure

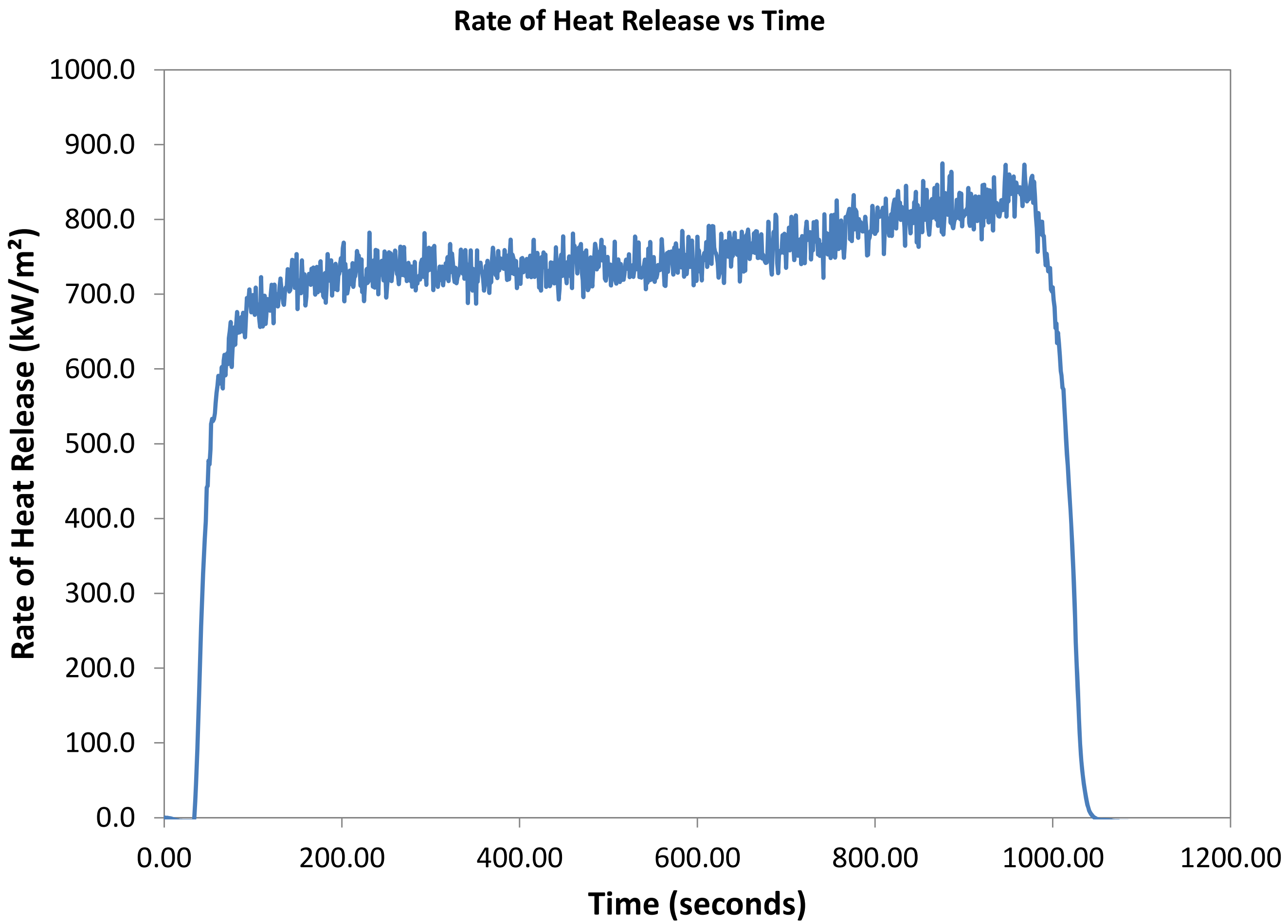
Data Analysis

Limitations

Sensitivity Analysis

Tips for Operation

Additional Information



Data Analysis

Background

Governing Principles

Operational Procedure

Data Analysis

Limitations

Sensitivity Analysis

Tips for Operation

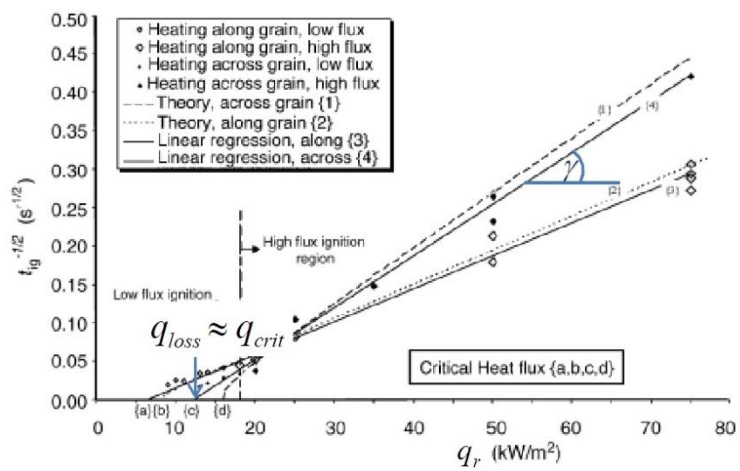
Additional Information

An analysis of the time to ignition can yield the thermal response parameter and the critical heat flux for ignition.

$$t_{ig} = \frac{4}{\pi} k\rho c \frac{\left(T_p - T_i\right)^2}{\left(\varepsilon q_r - \varepsilon\sigma T^4 - h(T_s - T_i)\right)^2}$$

$$\frac{1}{\sqrt{t_{ig}}} = \sqrt{\frac{4}{\pi}} \frac{1}{\sqrt{k\rho c}(T_p - T_i)} (\dot{q}_r'' - \dot{q}_{loss}'')$$

$$\frac{1}{\sqrt{t_{ig}}} = \sqrt{\frac{4}{\pi} \frac{1}{K}} (\dot{q}_r'' - \dot{q}_{loss}'')$$



Limitations

In the standard test, some limitations include:

- Significant intumescence prior to ignition will interfere with the spark igniter.
- Any change in the geometry of the sample makes changes the incident heat flux to the sample.
- Samples generally must be flat.
- Explosive spalling or exfoliation of the sample will limit the validity of the test.
- Significant melting and dripping while in the vertical orientation will yield unusable data.

Sensitivity Analysis

It is essential that the **oxygen concentration baseline** is steady and consistently realistic.

The **gas scrubbing chemicals** (Drierite and Ascarite) can affect the results.

Non-uniformity of the heat flux incident to the sample can cause non-one-dimensional effects.

Oxygen concentration is only slightly sensitive to the **exhaust flow rate**.

Tips for Operation

- Always video record tests and make notes about observations of events during experiments.
- Make sure the gas analyzer is properly purged during calibration and reaches the proper ambient value and zero point.
- Make sure water is always running through the heat flux gauge when setting the heat flux and that the distance from the heater to the heat flux gauge is consistent with the distance from the heater to the sample surface.
- Allow the chiller, load cell, and methane mass flow controller sufficient time to heat up before operation.

Additional Information

ASTM Standard E1354–11b, 2011. *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using and Oxygen Consumption Calorimeter.* ASTM International. West Conshohocken, PA, 2011

Twilley, William H. and Babrauskas, Vytenis. *User's Guide for the Cone Calorimeter.* NBS Special Publication 745. Gaithersburg, MD, 1988.

Quintiere, James G. 2006. *Fundamentals of Fire Phenomena.* Hoboken, NJ: John Wiley & Sons, Ltd.

Thank You!
Questions?