# Distribution Curves for Interior Furnishings on $CO_2$, CO, HCN, Soot and Heat of Combustion

by

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# Abstract

The purpose of this research is to develop a dataset for some of the most important fire characteristics, namely $CO_2$ yield, CO yield, HCN yield, soot yield and heat of combustion for probabilistic analysis and modelling.

Raw data in time series are required to mechanically reduce experimental data into yields (kg/kg) and effective heats of combustion (MJ/kg), which are expressions for the amount of products generated per unit mass of fuel. Mass loss rate thresholds were applied to all tests to define the beginning and end of tests. These species yields and heat of combustions were then grouped by material compositions and fitted with distribution functions to produce distributions curves.

As fire species productions and heat of combustions are dependent on the fire conditions as it develops, different yields are expected at different fire stages. These have been identified as the growth (G), transition (T), and smouldering (S) stages in this research. These values are also compared against, and are generally in agreement with, other research data. Nonetheless, some discrepancies have occurred and require further information to ascertain the material characteristics and combustion conditions.

In conclusion, design recommendations for these fire characteristics have been made for several material groupings and verified against other research results. Certain physical and chemical limitations exist for combustions and have not been reflected in the fitted distribution, including stoichiometric yields and unlimited air yields. As such, species yields and heat of combustions beyond these values should not be considered in fire engineering design and analysis.

Research results on HCN including all required data parameters for yield conversions were difficult to obtain and require further research efforts. Tube furnace results were initially investigated. Unfortunately, without a continuous mass record, has proved to be challenging in producing reliable mass loss rate profiles for yield conversions. A semi-automated data reduction application UCFIRE was also used. However, certain technical difficulties were encountered and require modifications to broaden its applicability.

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# 1 Introduction

Fires, especially unintended, are considered hazardous causing a great deal of damage to properties and environment, and can lead to injury or even death to people. Therefore, there is a need for accurate prediction of the impacts from fires on people and properties. This has become increasingly more important as performance-based fire safety engineering is more frequently used in many countries, including New Zealand.

Injuries or death by smoke inhalation has been the primary cause of deaths in fire. Both Gann *et al.*, (1994) and Hall (2005) reported nearly 75 percent all fire deaths occurred in places remote from the fire origin as smoke travels throughout the property. Therefore, apart from the heat released in fires, exposure to the toxic smoke must also be dealt with carefully to provide adequate life safety to its occupants. The purpose of this research is to develop a set of fire properties, namely $CO_2$ yield, CO yield, heat of combustion, and soot yield. The data collected consists of primarily residential items. However, the results of this research are also considered suitable for use by fire engineers and approving authorities on most commercial buildings as these also contain residential furnishings to various extents.

Smoke production characteristics, especially in an enclosed space, can significantly affect occupant escape abilities and tenability. The estimation of toxic gas emissions and heat generated from fires is important especially for egress modelling, where people are exposed to fire products. A reliable fire species yield input therefore becomes important in any fire engineering design to allow efficient fire escape design using simulation models.

As exposure to smoke and heat can cause different degrees of psychological and physical stresses that will impede the occupants' escape abilities. A sound understanding of key fire characteristics such as the types of and amounts of different species produced in fires is critical to ensure a realistic outcome of the fire engineering analysis.

Currently, only constant values can be used in different stages of fire, such as pre-flashover and post-flashover. However, various fire species yields are highly dependent of the fuel type, the pyrolysis rate, and the combustion conditions that are all expected to change during both the pre-flashover and post-flashover stages. Using constant values for each stage may either under- or over-estimate the fire species yields for escape designs.

## 1.1 Background

Exposure to smoke and heat in fires imposes different levels of psychological stresses on the escaping occupants, which may lead to incapacitation, possibly resulting in permanent injury or even death. According to Purser (2002), incapacitation effects can be categorised into three aspects of: toxic asphyxiant gas inhalation, optical obscuration due to soot production, and burns due to heat, including:

1. Impaired vision due to smoke obscuration (light scattering and optical opacity from soot production) and from the painful effects on the eyes caused by irritant smoke products and heat

2. Skin burns or hyperthermia, due to the effects of heat

3. Respiratory tract pain (or even burns) and breathing difficulties resulting from inhalation of hot irritant smoke. In extreme cases this can lead to incapacitation within a few minutes. Lung inflammation may also occur

4. Asphyxia from the inhalation of toxic gases, resulting in confusion and loss of consciousness

### 1.1.1 Toxicity

Thermal decomposition of almost every combustible material produces a smoke that is toxic. Studies have reported that fatalities not only occur in the room of fire origin, but also remote from it when the effects of fire spread outside the room of origin (Gottuk and Lattimer, 2002). Studies by Hall in 2005 has revealed that 75% of the victims died by exposure toxicant and smoke.

Psychological effects (outlined above) due to toxic smoke and heat exposures often occurring simultaneously in a fire. These can contribute to the loss of mental acuity and motor coordination, disorientations, panic, and eventually physical incapacitation (Hartzell, 2008). Delays or prevention of escape may lead to more severe injuries or death from further toxic smoke inhalation or thermal burns.

Causes and symptoms of toxic gases such as carbon monoxide and carbon dioxide are discussed later section 4.1, along with other substances that hinder occupant escape including soot and heat.

### 1.1.2 Probabilistic Design

As with any other models, fire safety modelling packages are only representative and useful when the appropriate input data are used, capturing all relevant aspects of associated uncertainties. When a fire burns, numerous chemical and physical interactions governing the combustion are constantly influenced by external conditions such as wind velocity and direction, humidity, ventilation and temperature that do not remain constant at any given point in time or space.

Since the fuel load, fuel package configuration and the burning state of the fuel continuously change during the combustion process, so do the combustion mechanisms, chemical exchanges and its surrounding environments continuously evolve. Naturally, a distribution of values would be expected from any fire event as a result of these influences. At the same time, a distribution of input values should be used in designs as this would better represent the actual fire event, as it gives a range of measured values.

Consequently, a probabilistic approach that gives quantitative values should be taken to present any data collected as it is “the most informative approaches to fire risk assessment in that they produce quantitative values” (Watts and Hall, 2002). The natural variability from each input parameter is represented probabilistically by individual distributions. When all relevant probability distributions are input into the model simulation, the output should capture a range of possible outputs to be expected from a similar fire event. To further increase the confidence of the output, repeated random sampling (Monte Carlo simulation) is executed. Only then can the fire hazard be "predicted within limits of confidence expressed in probabilistic terms" (Ramachandran, 2002).

### 1.1.3 Current Limitations on Data

Currently, some of most frequently quoted sources such as Tewarson (2002) and Mulholland (2002) have reported fire test results as single values. This is the most common reporting for deterministic designs, which can either be an average, or peak value (FASTData 1.0, 1999). Only a small portion of the literature has reported an associated standard deviation value (Gann *et al.,* 2003).

Due to inherent variability in combustion conditions including, but not limited to, instrumental set-up, and unknown response time (Enright, 1999), fire species productions can be expected to deviate away from its mean value during the course of the test. However, without an indication of the spread, fire engineering designs can potentially be unsafe or too conservative. Providing distribution inputs will give efficiency in design to provide safety at a potentially much reduced cost.

## 1.2 Impetus

Fire research in the past has placed significant emphasis on the flammability and heat release rates of materials. Since then, various research studies on species production (discussed in Chapter 4) have been conducted to quantify the reaction to fire behaviour of numerous products when exposed to thermal attack.

The fatal effects of toxic fire effluents have been examined and published individually by researchers across the world, including Gann (2004), Purser (2000), Brohez et al, (2000), Widmann et al. (2005), Stec and Hull (2008), and Andersson (2003). These research efforts were intended to evaluate the toxicity of fire effluents and its physiological effects on the occupants' escape abilities. More recently, a reference work edited by Stec and Hull (2010) was published to discuss the effects of fire effluent toxicity.

Furthermore, driven by the need for probabilistic analysis for engineering design purposes, it is important to not just understand the mean yield values but also its spread about the mean. However, standard deviations (or variances) associated with the reported values are not always available.

## 1.3 Scope and Objective

While many yield values are available from various literature and research programs, there has been little effort to report these experimental values in statistical terms, addressing the spread in terms of distribution shapes. The scope of the research is to provide such information, and comparing results from different research studies based on fuel types for free burning tests that are available during the time of this research.

At the moment, the fuel items of concern are weighted towards residential furnishings, as most data available were from residential items. Nonetheless, this does not necessarily limit the applicability of the database to residential buildings as previously explained. All fuel items were tested in the fuel-controlled, free burning regime for the following three fire species produced namely carbon monoxide, carbon dioxide, and soot, as well as heat generated from the fire. Frequently, smouldering combustion would occur toward the end of the combustion process due to charring of timber materials. Where considered relevant and still "effectively burning", these results will be included in this research work.

The objective of this research is to collect data that is currently available and transform them into yields. Design values of different fire effluent species (in the form of fitted distributions) based on different materials across different research organisations, testing methods, and scales of test for interior furnishings would then be recommended for performance-based designs. The creation of this database will also make the information more accessible for use in all areas of fire engineering, from research to consultancy, with results being reported in yields.

Firstly, this research provides a comprehensive literature review on the current research status and data available for analysis. Literature from a variety of research organisation was consulted, contact with the organisation followed if the work is considered relevant to the scope of this research. Due to various restrictions and lack of complete sets of data, a few sources could not be used during the course of this research. Follow-up is recommended to further enrich this database.

To provide an adequate database for fire engineering design, all data must be processed using the same data reduction methodology to ensure consistency. The step-by-step data reduction methodology adopted in this research transforms different reporting units into yields (kg/kg) for immediate comparison across different scales of tests. These reduced data are then presented in terms of fitted distributions as probabilistic model input for performance-based designs.

## 1.4 Overview of this Report

The body of this report gives a thorough and qualitative account of the steps taken to create this database for fire species yields. Chapter 2 contains the literature review on the work consulted to formulate this research project. Specific parameters required as well as the sources of data used to construct this database in discussed in Chapter 3.

To calculate the fire species yields, the formula are first explained in Chapter 4, followed by data reduction procedures in Chapter 5, detailing the criteria for data selection. Furthermore, to analyse the results in more detail, combustion is divided into three different stages of “growth (G)”, “transition (T)”, and “smouldering (S)” stages in Chapter 6.

After defining the material categorizations based on the data collected, a distribution fitting application (BestFit) was used to provide the best fit. Settings used to fit the data are outlined and discussed in Chapter 7, along with the broad material categorizations defined in this research. After the best-fitted distributions are found, the fitted distributions are compared against some literature values in Chapter 8.

Finally, limitations on the final result applications are discussed as governed by the physical limits on species yields. Other limiting factors such as simplifications and assumptions made during data processing are also discussed in Chapter 9. Design value recommendations as found from this research are given in Chapter 10, with references to Appendix A for more information. Chapter 11 concludes the findings of this research, with recommendations for future development.

# 2 Literature Review

According to Apte et *al,* (2005), “A design fire is a quantitative description of a fire that is representative of a particular scenario or sequence of events. The description is given in terms of the heat release rate history, production rates of various products, and the various combustion parameters, as well as the probability of the event or scenario. Typically this would form the basic input to a fire model describing a fire scenario, with the fire engineer deciding on the appropriate design variables and parameters to be used on any particular project”.

In order to compile a credible set of design inputs, a number of sources were consulted which guided and shaped the direction of this research work. Some provided relevant information for yield calculation (discussed in later chapters), while others provided yield values for comparison (Tewarson, 2002; Mulholland, 2002; Särdqvist, 1993). The creation of the database presented in this study largely relies on the background information derived from the literature below. Hence, a comprehensive account of each research is given, briefly discussing the contents and limitations of their experimental results.

## 2.1 Smoke Casualties

Based on qualitative estimates for smoke casualties in the United States and statistical findings for the United Kingdom and Australia, toxic smoke inhalation was determined to be the dominant cause of death in fires (Figures 2.1 and 2.3). Significant increases in smoke-related casualties have been linked with increase in both the use of synthetic materials and household furnishings and upholstered items, resulting in greater fuel loads.

### 2.1.1 United States Fire Statistics

According to Gann *et al*. (1994), “There is no single database in the United States that routinely and uniquely categorizes all fire deaths in terms of the nature of fatal injury (e.g. burns, smoke inhalation and fall)”. Despite this fact, several individual studies and databases have come close and agree that toxic smoke inhalation is the dominating cause of death (Berl and Halpin, 1979; Harwood and Hall, 1989).

Autopsy measurements focused on carboxyhemoglobin as an indicator of death due to carbon monoxide inhalation (Gann et al., 1994), based on a lethal carboxyhemoglobin threshold of 50%. This is because although hydrogen cyanide has been detected in fire victims, which is also a potent asphyxiant gas in fires (20 to 40 times more potent than carbon monoxide), the dynamic of its uptake and removal from the body is still poorly understood at this stage to be used as a suitable indicator.

### 2.1.2 United Kingdom Fire Statistics

The majority of fire-related deaths in the United Kingdom occur in dwelling fires, of which, the most common identified cause of death is being overcome by gas or smoke. This is demonstrated in Figure 2.1 and Figure 2.3, showing the highest percentage of fire victims are overcome by gas or smoke. A portion of the fire death has been categorized as “burns and overcome by gas and smoke”, where the relative contribution of each is left undetermined.

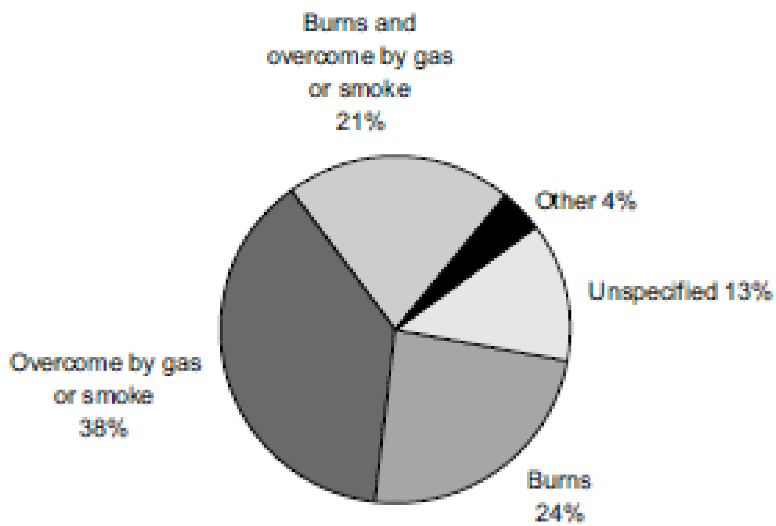



**Figure 2.1 Cause of Death for fire victims in the United Kingdom (1999) (Reproduced from United Kingdom Fire Statistics, 2002)**

Statistics from 1990 to 2000’s fire incident report for non-fatal injuries (Figure 2.2) further confirms smoke inhalation being the dominant cause of casualties in all fires.

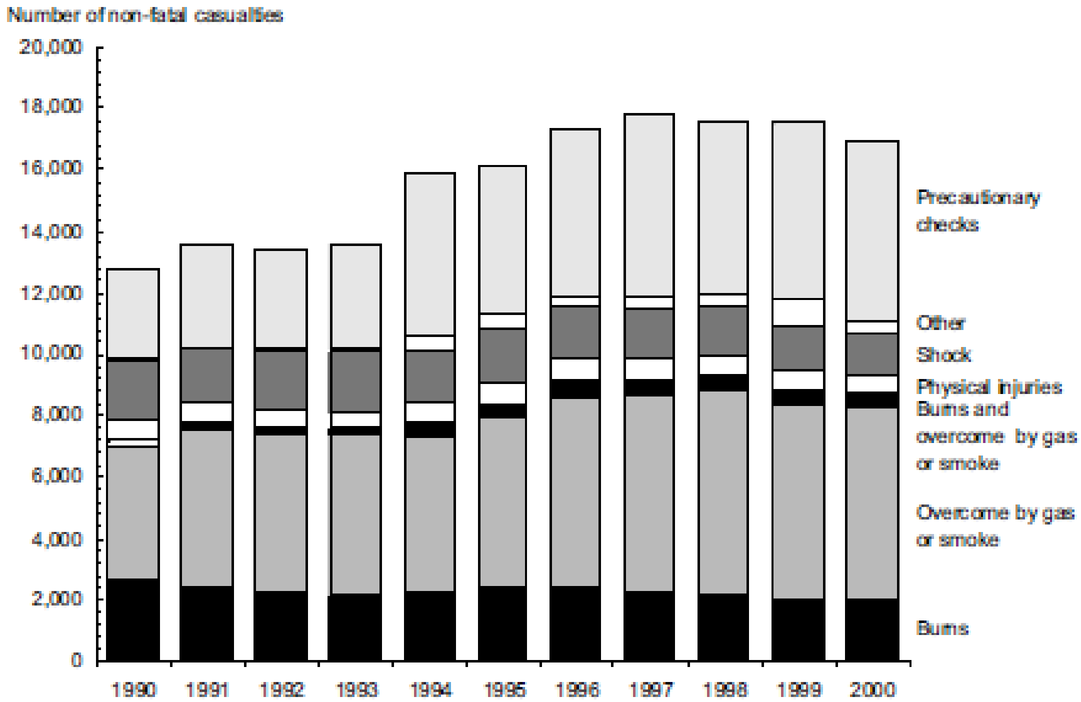



**Figure 2.2 Cause of Non-Fatal Injuries for fire victims in the United Kingdom (1990 to 2000)**
**(Reproduced from United Kingdom Fire Statistics, 1983)**

More recently in the 2004 fire statistics, similar conclusions can still be made with the majority of fire deaths and non-fatal injuries being overcome by gas or smoke in the United Kingdom. Figure 2.3 shows most fire victims in 2008 were overcome by gas or smoke, while Figure 2.4 shows that despite decreases in non-fatal fire injuries, the majority of the injuries were caused by toxic gases and smoke produced in fire (Fire Statistics, United Kingdom, 2008).

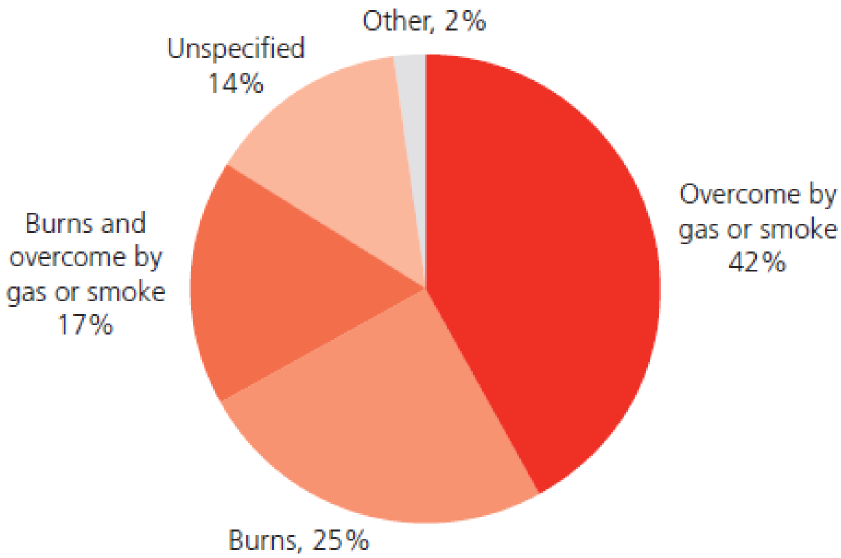



**Figure 2.3 Cause of Death for fire victims in the United Kingdom (1 Jan 2008 – 31 Dec 2008) (Reproduced from Fire Statistics, United Kingdom, 2010)**

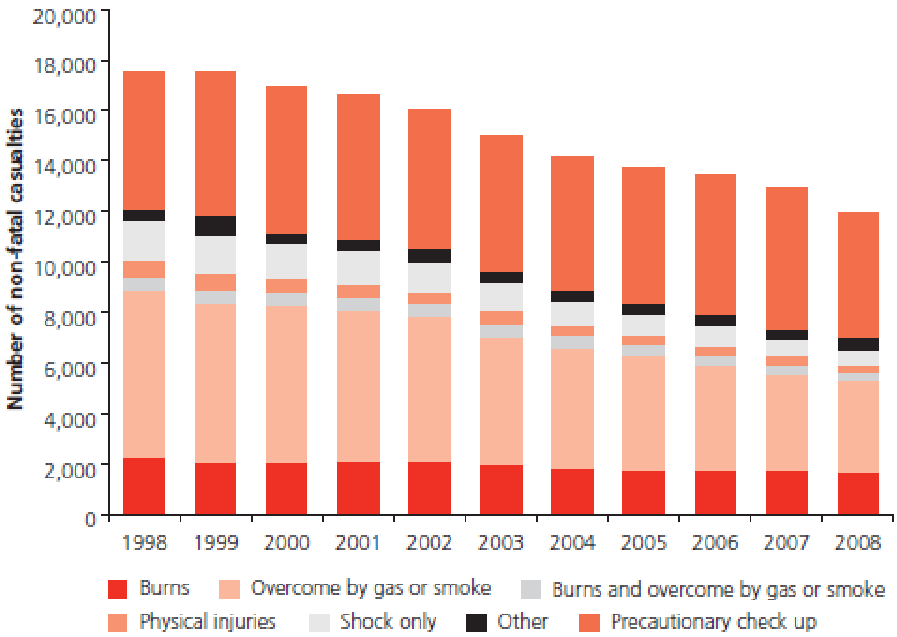



**Figure 2.4 Cause of Non-Fatal Injuries for fire victims in the United Kingdom (1 Jan 1998 – 31 Dec 2008) (Reproduced from Fire Statistics, United Kingdom, 2010)**

### 2.1.3 Australia Statistics

Statistical data summarised by the Queensland Department of Emergency Services reported all fire incidents that occurred from 1 July 1993 to 30 June 1996 for all States and Territories of Australia (Figure 2.5). Similar conclusion can also be made on the main cause of fire death being toxic smoke inhalation.

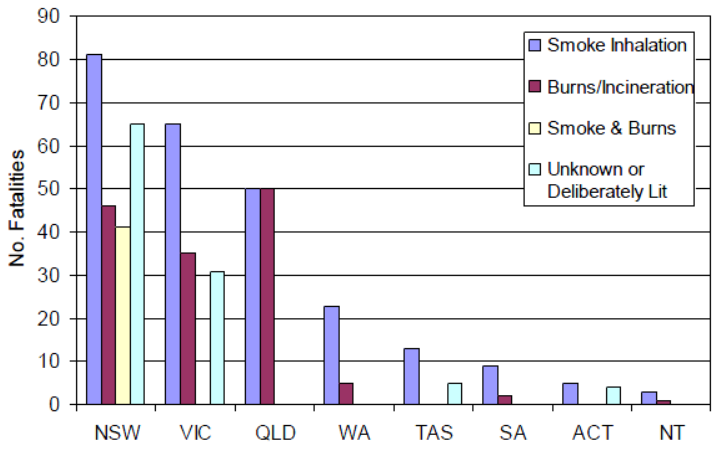



**Figure 2.5 Cause of Death for fire victims in Australia (1 July 1993 – 30 June 1996) (Reproduced from Apte et al., 2005)**

## 2.2 Tewarson's Research

A large collection of test results have been reported by Tewarson (2002) for fuels ranging from nylon to polyurethane foams to gypsumboards (GB). Most of the tests were performed under the ASTM E2058 (2009) fire propagation apparatus, with a small proportion of the tests derived from ASTM E1354 (2010) cone calorimeter test.

Tewarson has reported the results using various formats to cater for research and consultancy needs. The most relevant to this research is shown in Table 2.1, where $CO_2$ ($y_{CO2}$), CO ($y_{CO}$), and soot ($y_s$) yields as well as heats of combustion ($\Delta H$) are all reported as average values. The heat of combustion has been categorised into net heat of complete combustion ($\Delta H_T$), chemical ($\Delta H_{ch}$), convective ($\Delta H_{con}$), and radiative ($\Delta H_{rad}$) heats of combustion as shown in the second, seventh, eighth, and ninth columnsin Table 2.1. It should be noted that since combustion is never 100% complete, the experimentally measured effective heat of combustion ($\Delta H_C$) that is quoted in this research will always have an average value that is lower than the net heat of complete combustion ($\Delta H_T$) reported in Table 2.1 below (first column of data).

Table 2.1 is an example of some of the test results collected by Tewarson (2002). A large collection of combustion species yields and heat of combustions have been summarised and reported using average values for various fire engineering purposes. These tests were generally done under well-ventilated conditions. For restricted ventilation conditions, corrections have been made by Tewarson to reflect well-ventilated fire conditions (2002).

**Table 2.1 Yields of Fire Products and Chemical, Convective, and Radiative Heats of Combustion for Well-Ventilated Fires (Reproduced from Tewarson, 2002)**

| Material | $\Delta H_T$ (kJ/g) | $y_{CO_2}$ (g/g) | $y_{CO}$ (g/g) | $y_{ch}$ (g/g) | $y_s$ (g/g) | $\Delta H_{ch}$ (kJ/g) | $\Delta H_{con}$ (kJ/g) | $\Delta H_{rad}$ (kJ/g) |
|---|---|---|---|---|---|---|---|---|
| *Natural materials* | | | | | | | | |
| Tissue paper | — | — | — | — | — | 11.4 | 6.7 | 4.7 |
| Newspaper | — | — | — | — | — | 14.4 | — | — |
| Wood (red oak) | 17.1 | 1.27 | 0.004 | 0.001 | 0.015 | 12.4 | 7.8 | 4.6 |
| Wood (Douglas fir) | 16.4 | 1.31 | 0.004 | 0.001 | — | 13.0 | 8.1 | 4.9 |
| Wood (pine) | 17.9 | 1.33 | 0.005 | 0.001 | — | 12.4 | 8.7 | 3.7 |
| Corrugated paper | — | — | — | — | — | 13.2 | — | — |
| Wood (hemlock)[b] | — | — | — | — | 0.015 | 13.3 | — | — |
| Wool 100%[b] | — | — | — | — | 0.008 | 19.5 | — | — |
| *Synthetic materials—solids* (abbreviations/names in the nomenclature) | | | | | | | | |
| ABS[b] | — | — | — | — | 0.105 | 30.0 | — | — |
| POM | 15.4 | 1.40 | 0.001 | 0.001 | — | 14.4 | 11.2 | 3.2 |
| PMMA | 25.2 | 2.12 | 0.010 | 0.001 | 0.022 | 24.2 | 16.6 | 7.6 |
| PE | 43.6 | 2.76 | 0.024 | 0.007 | 0.060 | 38.4 | 21.8 | 16.6 |
| PP | 43.4 | 2.79 | 0.024 | 0.006 | 0.059 | 38.6 | 22.6 | 0 |
| PS | 39.2 | 2.33 | 0.060 | 0.014 | 0.164 | 27.0 | 11.0 | 16.0 |
| Silicone | 21.7 | 0.96 | 0.021 | 0.006 | 0.065 | 10.6 | 7.3 | 3.3 |
| Polyester-1 | 32.5 | 1.65 | 0.070 | 0.020 | 0.091 | 20.6 | 10.8 | 9.8 |
| Polyester-2 | 32.5 | 1.56 | 0.080 | 0.029 | 0.089 | 19.5 | — | — |
| Epoxy-1 | 28.8 | 1.59 | 0.080 | 0.030 | — | 17.1 | 8.5 | 8.6 |
| Epoxy-2 | 28.8 | 1.16 | 0.086 | 0.026 | 0.098 | 12.3 | — | — |
| Nylon | 30.8 | 2.06 | 0.038 | 0.016 | 0.075 | 27.1 | 16.3 | 10.8 |
| Polyamide-6[b] | — | — | — | — | 0.011 | 28.8 | — | — |
| IPST[b] | — | — | — | — | 0.080 | 23.3 | — | — |
| PVEST[b] | — | — | — | — | 0.076 | 22.0 | — | — |
| Silicone rubber | 21.7 | 0.96 | 0.021 | 0.005 | 0.078 | 10.9 | — | — |
| Polyetheretherketone ($PEEK\text{-}CH_{0.63}O_{0.16}$) | 31.3 | 1.6 | 0.029 | — | 0.008 | 17.5 | — | — |
| Polysulfone ($PSO\text{-}CH_{0.81}O_{0.15}S_{0.04}$) | 29.0 | 1.8 | 0.034 | — | 0.020 | 24.3 | — | — |
| Polyethersulfone ($PES\text{-}CH_{0.67}O_{0.21}S_{0.08}$) | 25.2 | 1.5 | 0.040 | — | 0.021 | 20.4 | — | — |
| Polyetherimide ($PEI\text{-}CH_{0.68}N_{0.05}O_{0.14}$) | 30.1 | 2.0 | 0.026 | — | 0.014 | 27.2 | — | — |
| Polycarbonate ($PC\text{-}CH_{0.88}O_{0.13}$) | 31.6 | 1.5 | 0.054 | — | 0.112 | 18.4 | — | — |
| *Polyurethane (flexible) foams* | | | | | | | | |
| GM21 | 26.2 | 1.55 | 0.010 | 0.002 | 0.131 | 17.8 | 8.6 | 9.2 |
| GM23 | 27.2 | 1.51 | 0.031 | 0.005 | 0.227 | 19.0 | 10.3 | 8.7 |
| GM25 | 24.6 | 1.50 | 0.028 | 0.005 | 0.194 | 17.0 | 7.2 | 9.8 |
| GM27 | 23.2 | 1.57 | 0.042 | 0.004 | 0.198 | 16.4 | 7.6 | 8.8 |
| *Polyurethane (rigid) foams* | | | | | | | | |
| GM29 | 26.0 | 1.52 | 0.031 | 0.003 | 0.130 | 16.4 | 6.8 | 9.6 |
| GM31 | 25.0 | 1.53 | 0.038 | 0.002 | 0.125 | 15.8 | 7.1 | 8.8 |
| GM35 | 28.0 | 1.58 | 0.025 | 0.001 | 0.104 | 17.6 | 7.8 | 9.8 |
| GM37 | 28.0 | 1.63 | 0.024 | 0.001 | 0.113 | 17.9 | 8.7 | 9.2 |
| GM41 | 26.2 | 1.18 | 0.046 | 0.004 | — | 15.7 | 5.7 | 10.0 |
| GM43 | 22.2 | 1.11 | 0.051 | 0.004 | — | 14.8 | 6.4 | 8.4 |
| *Polystyrene foams* | | | | | | | | |
| GM47 | 38.1 | 2.30 | 0.060 | 0.014 | 0.180 | 25.9 | 11.4 | 14.5 |
| GM49 | 38.2 | 2.30 | 0.065 | 0.016 | 0.210 | 25.6 | 9.9 | 15.7 |
| GM51 | 35.6 | 2.34 | 0.058 | 0.013 | 0.185 | 24.6 | 10.4 | 14.2 |

Although time series results were unavailable, the large collection of Tewarson's database has allowed several comparisons to be made for the distributions fitted in this work. It has also been a main source for fire engineering designs and model simulations (Parry et al., 2003; Roby et al., 2007; Saunders, 2010). Despite only reporting mean yield values, without an associated standard deviation to indicate its spread, it still provided an invaluable comparison to confirm that the datasets collected in this work are comparable to literature values (Chapter 8). Consequently, Tewarson's database validates the usefulness and credibility of the results presented in this research.

## 2.3 Mulholland's Research

Mulholland has taken a different definition from the American Society for Testing and Materials (ASTM) standards for smoke. Where all fire products from the fire are included as "smoke" by ASTM, Mulholland only considers the "smoke aerosol or condensed phase component of the products of combustion" (Mulholland, 2002). Thus, only soot particulates in the exhaust gas are considered in his research.

It is widely known that different amounts of smoke and fire species are produced under different combustion conditions (Gottuk and Lattimer, 2002). Mulholland's study on soot has confirmed the differences in soot yields under different combustion conditions through a comparison of smoke yields from different sources, as shown in Table 2.2 for a range of wood and plastic products. The terminology used in Mulholland's research for soot yield was the smoke conversion factor, $\varepsilon$, with a dimensionless unit, which is equivalent to the unit used for soot yield (kg/kg).

Noticeable soot yield differences have been observed under pyrolysis and flaming combustion conditions. For example, Douglas fir soot yield can be as much as 17 times higher (0.17) in pyrolysis condition than in flaming condition (<0.01).

**Table 2.2 Soot Yield Values for Wood and Plastics (Reproduced from Mulholland, 2002)**

| Type | Smoke Conversion Factor, ε | Combustion Conditions | Fuel Area, $m^2$ |
|---|---|---|---|
| Douglas fir | 0.03–0.17 | Pyrolysis | 0.005 |
| Douglas fir | $<$0.01–0.025 | Flaming | 0.005 |
| Hardboard | 0.0004–0.001 | Flaming[a] | 0.0005 |
| Fiberboard | 0.005–0.01 | Flaming[a] | 0.0005 |
| Polyvinylchloride | 0.03–0.12 | Pyrolysis | 0.005 |
| Polyvinylchloride | 0.12 | Flaming | 0.005 |
| Polyurethane (flexible) | 0.07–0.15 | Pyrolysis | 0.005 |
| Polyurethane (flexible) | $<$0.01–0.035 | Flaming | 0.005 |
| Polyurethane (rigid) | 0.06–0.19 | Pyrolysis | 0.005 |
| Polyurethane (rigid) | 0.09 | Flaming | 0.005 |
| Polystyrene | 0.17 ($m_{O_2} = 0.30$)[b] | Flaming | 0.0005 |
| Polystyrene | 0.15 ($m_{O_2} = 0.23$) | Flaming | 0.07 |
| Polypropylene | 0.12 | Pyrolysis | 0.005 |
| Polypropylene | 0.016 | Flaming | 0.005 |
| Polypropylene | 0.08 ($m_{O_2} = 0.23$) | Flaming | 0.007 |
| Polypropylene | 0.10 ($m_{O_2} = 0.23$) | Flaming | 0.07 |
| Polymethylmethacrylate | 0.02 ($m_{O_2} = 0.23$) | Flaming | 0.07 |
| Polyoxymethylene | ~0 | Flaming | 0.007 |
| Cellulosic insulation | 0.01–0.12 | Smoldering | 0.02 |

[a]Sample smoldered for a period of time after the pilot flame was extinguished.
[b]$m_{O_2}$ refers to mol fraction of $O_2$.

Nonetheless, users should be made aware that the great range for mean soot yields reported by Mulholland is a result of collapsing results conducted under different radiant fluxes, oxygen concentrations, sample orientations, and ambient temperatures into categories of material tested and combustion conditions. Similar to Tewarson's work (2002), only mean values are available as literature comparisons.

A brief comparison in made in Table 2.3 below between the soot yield values reported by Tewarson (2002) and the smoke conversion factor reported by Mulholland (2002) under flaming combustions. The results are in general agreement with each other being at least the same order of magnitude. However, significant soot yield differences is observed for flexible polyurethane, where Tewarson's soot yield is approximately ten times as high as Mulholland's smoke conversion factor.

**Table 2.3 Soot yield comparisons between Tewarson (2002) and Mulholland (2002) (Adapted from Tewarson, 2002 and Mulholland, 2002)**

| Material | Tewarson's (2002) soot yield values, $y_s$ (kg/kg) | Mulholland's (2002) Smoke Conversion Factor, ε (-) |
|---|---|---|
| Polyvinylchloride (PVC) | 0.172 | 0.12 |
| Polyurethane (flexible) | 0.131 – 0.237 | <0.01 – 0.035 |
| Polystyrene (PS) | 0.164 | 0.15 – 0.17 |
| Polypropylene (PP) | 0.059 | 0.016 – 0.10 |
| Polymethylmethacrylate (PMMA) | 0.022 | 0.02 |

Other properties of smoke such as size distribution, obscuration and detectability of smoke are also discussed in detail by Mulholland (2002). However, these are outside the scope of this research report, further information on these aspects of smoke can be found in Mulholland (2002).

## 2.4 Robbins and Wade's Research

The objective of Robbins and Wade's research was "to develop a fire engineering framework for performance-based design specifying design fire scenarios, design fire characteristics and acceptance criteria" (Robbins and Wade, 2008). With a focus on soot yield and its effect on occupant visibility, a variety of sources were consulted and converted to yields for comparisons (Figure 2.6).

In order to conduct a sensitivity analysis on smoke yield parameters using two commonly used fire models (FDS and BRANZFIRE), a set of soot yield values were collected from the CBUF research program (Sundström, 1995). Estimated soot yield values from the CBUF data set for furniture calorimeter tests (under flaming conditions) have been reported in the form of a histogram (Figure 2.6) for 25 items of upholstered furniture. Final soot yield recommendation was made by excluding the outlier caused by one single latex foam sample used in the CBUF program. This sample is not considered statistically appropriate to include due to lack of comparison as there were no other latex foams tested at that time since it was not commonly used in New Zealand furniture at that time. It is also in insufficient quantity to comprise a separate distribution for soot yield recommendation.

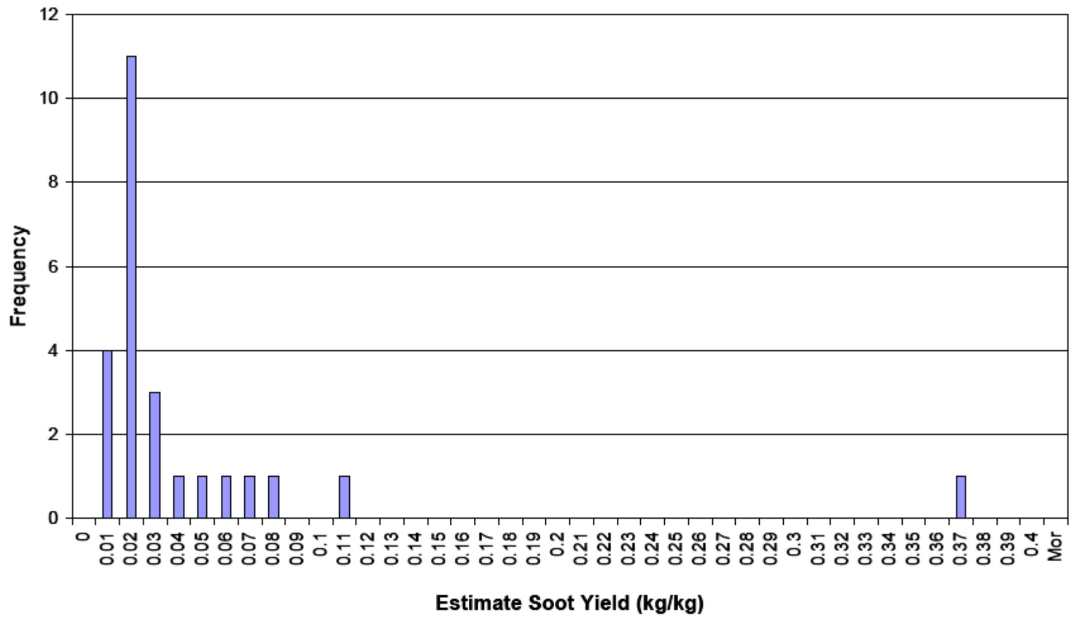



**Figure 2.6 Histogram of the estimated soot yield (kg/kg) for 25 CBUF furniture items (1995) (Reproduced from Robbins and Wade, 2008)**

Different sources and categories of estimated soot yields also available from Robbins and Wade (2008) including:

- Flaming combustion of a combination of materials (mattresses upholstered furniture),
- Flaming combustion of natural materials,
- Flaming combustion of synthetic solids and foams,
- Cone calorimeter tests for lining materials, and
- Flaming combustion for some typical products (timber, polyurethane foams, polystyrene etc)

While most values stated are for pre-flashover soot yields, some post-flashover soot yields are also available. Soot yields have been estimated by converting specific extinction areas (SEA, $m^2$/kg) and mass optical densities ($m^2$/kg) into soot yields. It should be noted that different sources referenced by Robbins and Wade (2008) have adopted different reporting units ($log_{10}$ and natural log), as well as using a different factor to convert obscuration measurements into soot yields. Most conversions had followed the CBUF protocol by adopting a divisor of 7,600 $m^2$/kg. However, cone calorimeter tests for lining materials (Wade and Collier, 2004) have used a divisor of 8,790 $m^2$/kg to estimate soot yields. Details on soot yield conversions can be found in Chapter 4.

When compared to experimental results, both the FDS and BRANZFIRE models produced conservative predictions of smoke optical density for a flaming upholstered armchair. Only model predictions based on the lowest soot/smoke yield of 0.05 kg/kg provided the closest agreement, yet it was still considered conservative comparing to the experimental results. This indicates using some of the literature average values may be too conservative for design purposes.

It has been acknowledged by Robbins and Wade that this study has only incorporated a small range of scenarios; therefore, caution must be taken when applying conclusions from this report to other situations. Further areas of research identified by Robbins and Wade (2008) include considerations for post-flashover soot yields, and for a wider range of scenarios and building layouts.

## 2.5 Wade and Collier's Research

In Wade and Collier's research (2004), BRANZFIRE model predictions (using zone model techniques and thermal flame spread theory) were compared against ISO 9705 room-corner tests for smoke obscuration effects under relatively well-ventilated conditions. Model input for soot yield values were derived from a series of surface lining tests reported as SEA ($m^2$/kg) by Heskestad and Hodve (1993). The results were then compared to the room-corner tests carried out as part of the EUropean REaction to FIre Classification (EUREFIC) research (1991).

To estimate soot yield from SEA under well-ventilated conditions, all SEA values reported by Heskestad and Hodve (1993) were divided by a constant of 8790 $m^2$/kg based on Mulholland and Choi's research findings (1998). This is one of the many divisors proposed and adopted by the fire engineering community. More discussions on the different divisors can be found in Chapter 4.

The zone model predictions based on cone calorimeter soot yields were found to be satisfactory for the materials tested under well-ventilated cases. However, the accuracy of the predictions depends on having sufficient cone calorimeter data for the material of interest. Development and verification of the smoke prediction capabilities of BRANZFIRE for both ventilation conditions were recommended, particularly for under-ventilated conditions.

## 2.6 Initial Fires

The Initial Fires report was intended as a guide in estimating how a fire can be characterised as the first item to ignite, and its rate of growth. Based on published and unpublished full-scaled tests at several different laboratories, the Initial Fires database (1993) covers a wide range of items, from lining materials and pallet systems to chairs, curtains and coffee makers. Some rates of smoke production and toxic gas productions, such as carbon monoxide are also described where available.

Unfortunately, as mass records are not available as shown in Table 2.4 for the technical fittings sample ("Y1", item 40), data from the Initial Fires database could not be implemented into this research report. Nonetheless, mean values reported have provided useful comparisons to validate the distributions fitted in this research. Agreements have been found for non-fire retarded foams and beds considered in this work. Chapter 8 discusses these comparisons in more detail.

**Table 2.4 Exemplar Initial Fires Database Format for Technical fittings ("Y1"), item 40 (Reproduced from Särdqvist, 1993)**

| Y1/40 | | | |
|---|---|---|---|
| T (s) | RHR (kW) | S (obm3/s) | CO (l/s) |
| 0 | 0 | 0 | 0 |
| 30 | 10 | 0.5 | 0 |
| 60 | 50 | 3 | 0.5 |
| 90 | 100 | 9 | 1 |
| ... | ... | ... | ... |
| -9 | -9 | -9 | -9 |

A need for additional tests has been identified in the Initial Fires database. Items such as upholstered chairs had been tested in a variety of configurations and combinations, while other items appear rarely in the test records. These include industrial machineries, vehicles, storage units (with different goods), and wardrobes (with clothes). In the context of residential furnishings, similar gaps have also been identified, such as curtains and drapes television sets and more.

## 2.7 Young's Research

Driven by the demand for data to facilitate more efficient performance-based designs, Young focused her research on the heat release from fires. Before then, there has been no standardisation for design fires. Consequently, this has led to "different fire safety designers using different fire characteristics for their fire safety analysis and a lack of uniformity in the levels of safety provided" (Young, 2007).

With the publication of Young's work, a set of furniture design fires for residential/apartment buildings have become available. General fire characteristics identified and discussed by Young include: peak heat release rate, time to peak heat release rate, and the total heat released for different types of furniture items. A significant emphasis has been placed on upholstered furniture as more research data were available. Table 2.5 summarises the collection in Young's database, including free burning items and room fires.

**Table 2.5 Data Available in Young's Database (Reproduced from Young, 2007)**

| Classification | Number of Items |
|---|---|
| Free Burn | 176 |
| Room Burn | 86 |
| **Item Description** | |
| Armchair | 210 |
| 2-seater sofa | 23 |
| 3-seater sofa | 11 |
| Mattress (& base) / Bed & Bedding | 18 |
| **Total** | 262 |

Only mean heat release rates were collected from literature and existing databases. Hence, the distribution profiles represent the spread of mean values for similar products of different fuel compositions. Consequently, the spread observed is largely attributed to differences in the fuel package. Figure 2.7 below presents Young's armchair collection for peak heat release rates.

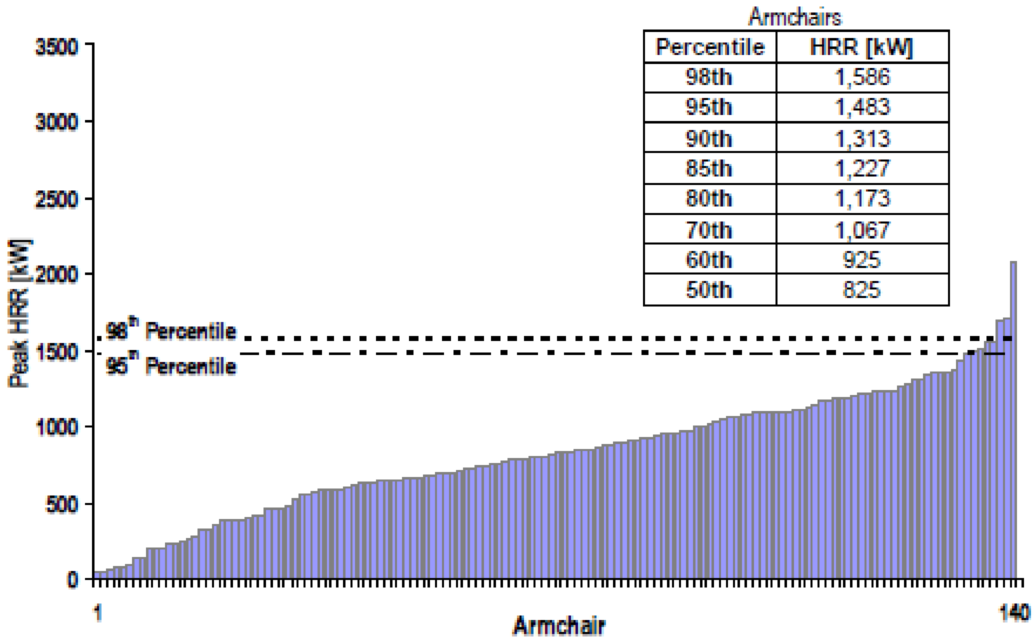



**Figure 2.7 Peak Heat Release Rate for Armchairs**
**(Reproduced from Young, 2007)**

Further to the heat release rate database, Young also determined a methodology for incorporating compartment effects in design fires, based on data from CBUF, the University of Canterbury, and a few sources from NIST. Information on compartment effect can be found from Young's research report (2007)

The outcome of this research on fire species production would complement Young's studies (2007) on heat release rates for residential buildings and apartments. Consequently, this would provide greater consistency in design safety levels through recommending design values from fitted distributions.

# 3 Essential Data Parameters and Sources

All test results obtained in this research were conducted either using a cone calorimeter or a furniture calorimeter involving different sample scales, following their respective standards (ISO 5660, 1993 and NT FIRE 032, 1987).

To conduct a fire test using a calorimeter, the sample must first be calibrated using a known concentration calibration gas and known output burner to ensure accurate readings during the tests. Burning is initiated by an ignition pilot for both the cone calorimeter tests and the furniture calorimeter tests (either using an electrical cone heater or various forms of pilot igniters such as an impinging flame or glowing wires). Once the ignition is successful, combustion products will rise up as smoke into the collection hood and be measured. Transportation and instrumental lags for various combustion products exist due to physical transportation of the combustion products and instrument which are different for different fire species and experimental configurations that must be accounted for in all tests.

Data parameters critical for yield calculations are discussed in the first part of this chapter, followed by brief introduction to the data sources used in this research, and data sources that could not be used in this research as they lack at least one of the critical data parameters discussed in section 3.1.

Due to time and resource constraints, some data that could not used or obtained in time during the course of this research are also discussed and appended in Appendix B. These data source can be considered as the first step to expand the current database to include more overseas data, in order to broaden the applicability of this database.

## 3.1 Essential Data Parameters

To accurately determine fire species yields, various experimental factors must be considered and accounted for. These include:

- The calibration data,
- The effects of igniter or burner, in terms of heat output, duration, and method of ignition, and
- Time delays for the combustion products to physically travel to the sensor and be registered by the instruments

Although it is preferable to have all the above data, not all data acquired include these parameters. For example NIST's FASTData collection (1999) has all quantities converted into yields with smoke measurements being reported as specific extinction areas (SEA, $m^2/kg$). It is assumed that these processed data have included the appropriate time delays and removed the effects of any burner outputs.

For the other raw data obtained, the following time series are required to mechanically reduce the experimental data into yields (kg/kg) and effective heats of combustion (MJ/kg):

- The mass record,
- The mole fraction of gas species,
- Soot production,
- The heat release rate, and
- The mass flow rate through the calorimeter's exhaust duct

### 3.1.1 Calibration Data

Calibration is a crucial procedure for every experiment; a calibration procedure is given below for experiments conducted at the University of Canterbury (Dunlop, 2010). The cone calorimeter is calibrated every day before use with ultra high purity methane for the heat release rate, while an alpha standard calibration gas is used for the analysers. Concentrations of $CO_2$, CO, and $O_2$ in the calibration gas are such that it sets the upper limits of the analyser. The furniture calorimeter analysers are also calibrated every day of use, using and alpha standard gas and nitrogen gases. For heat release rate, the furniture calorimeter is calibrated at the start of any research project, then periodically through the project duration using propane fuel. Where calibration data is available, it is used to calibrate experimental measurements for calculating various fire species yields and to determine time delays.

### 3.1.2 Effects of Ignition Sources

In order to accurately account for the amount of heat and combustion products released, the amount of heat and the combustion products released from the ignition source must be removed to accurately measure the species productions from the fuel of interest alone. Many different types of burners have been used in the database collection, including electrical matches, matches, fire starters, and the square ring burner complying with CBUF protocol requirements (Enright, 1999; Denize, 2000; Hill, 2003). Between each ignition source, there is a significant difference in terms of heat release rate and gaseous species production, which all need to be accounted for.

In this research, the beginning and end of test are both defined as a function of mass loss rate (Chapter 5). Where a minimum mass loss rate threshold is used to define when an item is effectively burning. Therefore, as will be demonstrated in later chapters, the ignition periods were all completely removed from all tests since the item of interest is not losing much mass itself due to combustion.

### 3.1.3 Time Delays

As the test results are time-dependent, time delays should be properly accounted for to account for measurement offsets. An example is the difference between the mass loss measured on the mass scale (instantaneous) and the mass flow registered by the sensors in the exhaust duct. This is because time is required for the combustion products to physically reach the collection point in the duct, and to be processed and registered by the instruments.

Thus, time delay is primarily made up by two types of lags that: transportation lag and response lag. Transportation lag occurs as various fire effluents need to travel from the fire origin to physically reach the measuring instruments. Response lag is the time required for the measuring instrument to receive and register the readings, and is assumed to behave exponentially. Typically, these two quantities are summed and reported as a single value (Enright, 1999). Time delays for cone calorimeter tests are usually relatively constant, as the configurations are fixed most of the time. Experiments of other configurations would require individual assessment from the calibration files as part of the initial setup.

Time delays are not constant for different properties of interest, such as the pressure, temperature, and species concentration. Therefore, these must be incorporated separately to ensure accuracy in these time-dependent variables. Where sufficient information is available, time delays were incorporated into the time series to facilitate calculations such as heat release rate, and species yields. Otherwise, it is assumed that any delays have already been included in the time series such as the data obtained from Madrzykowski and Kerber (2009). For more information with regards to time delays, consult Enright's work (1999).

### 3.1.4 Mass Record

Yield is an expression for the amount of products generated from a given amount of mass, therefore, the rate at which combustion products are being generated must be divide by the rate at which mass is lost to calculate the yield for a particular combustion product yield. In order to avoid extremely high or low yields, the mass records were smoothed using moving averages to remove the inherent instrument fluctuations, followed by moving gradient calculations over 30 seconds to calculate mass loss rates (Chapter 5). This was especially important for experiments recorded at short time intervals, such as 1 second, as any changes over a short timeframe are comparatively insignificant and may be overwhelmed by instrumental or external fluctuations.

The smoothing effects will minimise these effects to reveal the underlying mass changes. Similarly, to minimise the effects of reading fluctuations, mass loss rate is calculated taking mass readings 15 seconds before and after the time of concern to calculate its gradient, hence the mass loss rate at that point in time. These are necessary procedures to prevent inaccurate and hazardous conclusions being drawn from this research. Further details on the procedure can found in Chapter 5.

### 3.1.5 Mole Fraction of Gas Species

Mole fractions of gaseous species have been calibrated using the calibration data to give measurements as a fraction of the total mass flow through the calorimeter's exhaust duct. These are typically expressed as percentages (%), or parts per million (ppm) for trace species. Gases species of interest include: oxygen ($O_2$), carbon dioxide ($CO_2$), and carbon monoxide (CO).

### 3.1.6 Soot Production

Soot productions were measured optically and have been reported as specific extinction areas (SEA, in $m^2/kg$), and smoke production rates (SPR, in $m^3/s$). To convert these optical obscuration measurements into soot yields, a constant divisor is used. Chapter 4 provides a discussion on the range of divisor values proposed by different researchers. The smallest divisor (7,600 $m^2kg$) has been used to convert SEA in to soot yield in this research, providing the most conservative estimation.

### 3.1.7 Heat Release Rate

As one of the most critical characteristic of any fire (Babrauskas and Peacock, 1992), heat released is also measured. It is calculated using oxygen consumption, a theory first discovered by Thornton (1917) which propose a more or less constant net amount of energy is released per unit mass of oxygen consumed. This is later established by Huggett in 1980, and found that on average, 13.1 MJ of energy is released from every kilogram of oxygen (Huggett, 1980). In this manner, the measured quantity is the effective heat released, which is the heat of combustion which would be expected in a fire where incomplete combustion takes place, which is a more realistic fire situation.

For a detailed description of the background to the calculation of the heat release rate, refer to Janssens and Parker (1992).

### 3.1.8 Mass Flow through the Exhaust Duct

To calculate the quantity of the gaseous fire species, the mass flow rate must be known. This is because all species are expressed as a fraction of the total mass flow rate measured at the exhaust duct. Mass flow rate through the duct varies throughout any experiment depending on the airflow temperature, which changes with the heat release rate. In other words, it is an important time-dependent variable that is sensitive to how the item is burning, which cannot simply be expressed by a constant value.

## 3.2 Sources of Data Used

A variety of data sources have been included in this research, from bench scale tests under the cone calorimeter to full scale tests under the furniture calorimeter.

### 3.2.1 Cone Calorimeter Tests

End of tests were defined by ISO 5660 (1993) by either one of visual assessment, mass loss rate threshold, or time limit criteria, stating the end of the test is considered to be:

1. After all flaming and other signs of combustion cease
2. While there may still be vestigial combustion evidence, but the mass loss rate has become less than 150 $g/m^2$ being lost during any 1 min, equivalent to 2.5 x $10^{-5}$ kg/(s $0.01m^2$)
3. 60 min have elapsed

The second criterion using the mass loss rate threshold has been applied to define the beginning of tests, especially the mass loss criterion since most tests do not have a visual record, nor do they last more than 60 minutes. Exceptions occur with NIST's FASTData (1999) where only highly fluctuating mass loss rates were given, preventing a distinctive start and end of test definition. In this case, the entire time series was included in the final analysis and subsequent distribution fitting.

Where retainer frames were used, the sample area was adjusted to 0.0088 $m^2$, giving a lower mass loss rate limit of 2.2 x $10^{-5}$ kg/(s $0.0088m^2$). As the extent to which a retainer frame may affect item burn is unknown, a lower mass loss rate limit is conservatively used to account for all factors that might influence the combustion dynamics.

A brief account of each cone calorimeter data source is given below. Different incident heat fluxes have been applied to a wide range of interior furnishing products. This includes a variety of foam and fabric combinations, wall and ceiling lining materials, and carpets.

### 3.2.1.1 NIST FASTData – Foam and Fabric Combinations

A large number of cone calorimeter tests were conducted at NIST as an effort to correlate large scale test results from small scale test results. A variety of foam and fabric combinations were tested for 27 fabrics / barriers / polyurethane foam combinations (seven fabrics, four barriers and two polyurethane foams) that were considered representative of typical U.S. furniture items at that time. Details on these cone calorimeter tests can be found from Ohlemiller and Shields' NIST report (1995).

Tests from the FASTData database gave species yields without the mass flow rate through the exhaust duct records and the species production rates. Consequently, time delays associated with the cone calorimeter used are assumed accounted for prior to the yield conversion. Nonetheless, the smoothing procedures (discussed in Chapter 5) that has been applied to mass record from the rest of the data sources could not be applied to these FASTData tests.

It is worth noting that perhaps limited by instrumental or computational capabilities; measurements were only recorded every 5 seconds. With many tests being less than 60 seconds long, some yield values fluctuated significantly from their adjacent values (FASTData, 1999). This is because combustion is a complex and rapid reaction; a 5 second gap in time would not be able to capture the details of these species productions. Furthermore, the lack of mass loss rate smoothing procedure also means fluctuations from instrumental measurements could not be reduced to better reveal the underlying yield profiles.

#### 3.2.1.2 Firestone – Foam and Fabric Combinations

A series of foam and fabric combination tests were done by Firestone (1999) at the University of Canterbury to analyse the bench-scale to full-scale combustion behaviour predictions for a series of furniture specimens. Two foams were considered in Firestone's research, these were a "High Resilience Polyurethane" and "Standard Polyurethane", covered with either 100% polypropylene fabric, 100% cotton/linen fabric, or without any covering fabric.

Firestone's cone calorimeter results from the University of Canterbury were found to be comparable with similarly constructed and tested samples done by the fire-testing laboratory at Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Melbourne, Australia. Some furniture calorimeter tests were also done at CSIRO for the same foam and fabric combinations tested in small scale. Unfortunately, both CSIRO's cone calorimeter and furniture calorimeters tests do not have complete mass records, and could not be used in this research work (refer to section B.1.4 for more detail).

### 3.2.1.3 Bong – Reconstituted Timber Weatherboards (“Weathertex”)

As a study to determine BRANZFIRE’s flame spread model, a selection of four cladding materials were tested both in bench-scale and in a vertical full-scale testing rig at BRANZ (Bong, 2000). Only cone calorimeter results for the reconstituted timber weatherboards were available, which were exposed to irradiances ranging from 25 $kW/m^2$ to 70 $kW/m^2$.

### 3.2.1.4 Collier, Whiting and Wade - Wall and Ceiling Lining Materials

The main objective of this BRANZ project (Collier *et al*., 2006) was to demonstrate the effectiveness of two different scales of fire testing methods in evaluating the reaction-to-fire performance. A selection of surface lining materials available in New Zealand were tested in the ISO 9705 room and the ISO 5660 cone calorimeter as applied to walls and ceilings.

Due to excessive smoke production when testing plywood with different layers of intumescent paint, experimental data for items 3 and 3a were highly distorted (Table 3.1). This was considered inappropriate for the purpose of this research therefore not considered in this work, leaving nine of the eleven sets of cone calorimeter test results shown in Table 3.1 usable, each with 3 replicate tests exposed to an irradiance of 50 $kW/m^2$.

**Table 3.1 Products tested using the ISO 9705 room corner method and the AS/NZS 3837 cone calorimeter (Reproduced from Collier *et al.*, 2006)**

| Product |
|---|
| 1. Vinyl wallpaper glued onto plasterboard |
| 2. Plywood |
| 3. Plywood+intumescent paint (2) |
| 3a.Plywood+intumescent paint (3) |
| 4. Glazed fibre-cement board – fixed to steel studs |
| 5. Plastic co-polymer fixed to studs |
| 6. 3 mm polyester fibre wall covering fabric glued onto plasterboard |
| 7. 12 mm 100% modified polyester wall covering glued onto plasterboard |
| 8. Rubber based noise barrier – glued onto plasterboard |
| 10. 13 mm softboard+paint |
| 11. 13 mm softboard |

#### 3.2.1.5 Johnson – Carpets (Unpublished Results)

The purpose of Johnson's research (2008) was to determine carpeted stair performances in bench- and full-scale tests. Four types of carpeting materials of: nylon, polypropylene, wool, and wool/polypropylene were tested under four irradiance levels ranging from 20 kW/m$^2$ to 70 kW/m$^2$. Samples were also tested in vertical orientation; however, no mass records were available for vertically-oriented sample. Furthermore, full-scale test results were not available due to premature termination of this research.

### 3.2.2 Purpose-Built Item Tests

Although purpose-built chairs are usually not representative of the fire hazards in real life, they are however, a more cost-effective method to evaluate the effects of various factors influencing one or more of the many combustion behaviours.

#### 3.2.2.1 Collier and Whiting – Purpose-Built Polyurethane Chairs

Twelve medium-scaled purpose-built chairs were tested by Collier and Whiting (2008) at BRANZ to determine the effects of ignition sources and ignition locations have on the timeline for incipient fire development. Two different ignition sources (match and fire starter) and three ignition locations (centre of seat cushion, junction of cushions, and front edge of seat cushion) were investigated.

All tests were conducted as free burning tests under the extraction hood of the ISO 9705 testing apparatus. Heat release rates, gas productions, mass records, and smoke extinction areas were recorded, analysed and presented as statistical distributions by Collier and Whiting (2008).

Unlike large scale tests such as Enright's (1999) and Hill's (2003) tests, steel frames were used instead of wooden frames to support the two seat and back cushions, which are made of polyester-fabric covered polyurethane foams (Figure 3.1). The average total combustible mass (foam, wadding and fabrics) weighed just below 2kg (Collier and Whiting, 2008).

To verify results from these purposed built tests, three real sofas of predominantly foam construction were also tested. These sofas were much heavier at approximately 20kg and are discussed in more detail in section 3.2.3.4.


**Figure 3.1 Purpose-built Upholstered Chair (typical of tests 1 to 12) (Reproduced from Collier and Whiting, 2008)**

### 3.2.3 Furniture Calorimeter Tests

Since it was first discovered to be an important issue in late 1960s and early 1970s, the flammability of upholstered furniture has raised many concerns. As such, most fire tests performed in the last few decades have been focused on upholstered item combustions normally found in interior furnishings.

A few sources of large scaled tests have become available for this research work through the University of Canterbury, BRANZ, and NIST. All tests were either tested in the furniture calorimeter (NT FIRE 032, 1987) according to the CBUF protocol, or under the extraction hood of the ISO 9705 apparatus (as free burning tests). Each research had a different objective, from verifying bench-scale predictions (Denize, 2000) to investigating combustion behaviour under wind-driven conditions (Madrzykowski and Kerber, 2009).

Due to the greater amount of fuel involved, different stages of the fire were more easily identified, from the initial growth stage through the transition stage to the final smouldering combustion stage of the wooden frames. The longer timeframe also gave steadier yield profiles and more realistic yields, compared to similar items tested in smaller scales such as the foam and fabric combination tests by Firestone (1999).

#### 3.2.3.1 Enright – New Zealand Upholstered Furniture

As an initiative to verify the applicability of the CBUF model to exemplary New Zealand furniture, bench-scale furniture composites and full-scaled furniture items were tested by Enright (1999) according to the CBUF protocols (Sundström, 1995).

Both CBUF model I and II were applied to these exemplar New Zealand furniture item, and it was found that "New Zealand furniture consistently exhibits higher peak heat release rates for similar total heat" (Enright, 1999). As a result, "exemplar New Zealand furniture presents a significantly greater fire hazards than its European counterparts" (Enright, 1999).

Only 10 of the full-scale furniture items have become available for this research, of which, the two-seater tests could not be used, leaving eight sets of results suitable for this research. The reason being the heat release rate generated from these larger fuel loads had overwhelmed the extraction hood and spilled under the edge.

The material compositions included combinations of two foam types (polyether foam pad and generic PU foam) and five covering fabrics (polyester and blended fabrics, nylon pile with polyester backing, polypropylene fibre, nylon pile 65/35 polyester-cotton back, and nylon piles) with and without the fibre inter-liner wrap (not specifically fire-retarded).

#### 3.2.3.2 Denize - New Zealand Upholstered Furniture

To evaluate combustion severity of New Zealand upholstered furniture materials, 63 bench-scale cone calorimeter and 10 full-scale furniture calorimeter tests were tested by Denize (2000) in order "to improve predictive full-scale behaviour models from bench-scale data". Foam and fabric selections were made based on commonly used compositions, to adequately cater for real life hazards encountered in commercial and domestic setting in New Zealand. Test results available include two types of covering fabrics (polypropylene or wool 95/5 synthetic material) and five types of polyurethane foams listed below:

- Domestic Furniture Foams,
- Superior Domestic Furniture Foams,
- Superior Domestic Furniture Foams (Fire retarded),
- Public Auditorium Seating Foams, and
- Public Auditorium Seating Foams (Fire retarded)

Cone calorimeter tests for the same foam and fabric combinations were also conducted by Denize (2000), unfortunately, these data is not available during the course of this research.

### 3.2.3.3 Hill – New Zealand Upholstered Furniture

More than 50 full-scale tests were conducted by Hill (2003) to study burning behaviour of common New Zealand upholstered furniture items. Different foam, fabric, and style combinations were tested, of which, 38 test results were available with video footages and still photographs at 30s intervals. The foams and fabrics tests collected from Hill's tests are tabulated in Table 3.2 below:

**Table 3.2 Foams and Fabrics tests collected from Hill's (2003) Large Scale Tests**

| Foams | Fabrics |
|---|---|
| Aviation Foams | Polypropylene |
| Domestic Furniture Foams | Wool |
| Public Auditorium Seating Foams | |

It is interesting to note that natural fabrics (i.e. wool) coupled with aviation foam tend to produce an initial small peak followed by a much delayed and larger second peak in heat release, if successfully re-ignited. The charring property of these natural fibres had restricted burning rate, giving poor horizontal flame spread to significantly decrease fire intensity.

### 3.2.3.4 Collier and Whiting – Real Sofa Chairs

In addition to the purpose-built medium scale tests, three large scale sofa chairs of predominantly foam construction (without any covering fabric) were also tested by Collier and Whiting (2008), to verify the medium-scale test results. Further details on the sofa construction were unavailable. It was assumed that a wooden frame was used to support the sofa, as per typical upholstered chair.

### 3.2.3.5 Madrzykowski and Kerber – Residential Furnishing Items

In order to quantify baseline conditions for comparison to wind-driven fires, four different types of items were tested in the furniture calorimeter by Madrzykowski and Kerber (2009). The items chosen were typical residential furnishings as listed below. Each item had two replicates, yielding eight sets of test results.

- Two trash containers filled with dry, flat-folded as well as crumpled newspapers
- Two king-sized innerspring mattress beds on wooden frame with all beddings components. Based on the manufacturers tag, the combustible material in the mattress consist of 49% blended cotton felt and 51% polyurethane foam
- Two upholstered chairs with arms of polyurethane foam and polyester fibre fabric construction, supported by hardwood frames
- Two sleeper sofas predominantly composed of polyurethane foams and polyester fabrics on “wood frame surrounding a metal foldout sleeper sofa mechanism and foundation” (Madrzykowski and Kerber, 2009)

# 4 Fire Species Yields

Exposures to toxic smoke can cause varying levels of psychological stresses, from irritation, hyperventilation, burns, and incapacitation. The effects of these fire species are inter-related and considered approximately additive. Survival in a fire situation depends on two parallel events. These being: the developing hazard from the fire, and the process by which occupants escape (Purser, 2002), also known as the Available Safe Egress Time (ASET), and the Required Safe Egress Time (RSET), respectively. To model both ASET and RSET for occupant escapes, the amounts of these toxic productions must be known accurately.

To assess the toxic potency of each gas, which is the amount needed to be dispersed into 1 $m^3$ in order to cause a 50% probability of lethality, a number of physical fire models have been developed. Limited by the scope of this research, an overview on these fire models can be found from Guillaume and Chivas' paper (2008). Once the toxic potency of these fire species are determined, the intake amounts are weighted accordingly and calculated using the equations proposed by Purser (2002). This quantity is calculated for every time frame, which is integrated over time to calculate the final Fractional Effective Dose (FED) at that point in time. As a mixture of gases is often present in any fire, to calculate the interacting effects of different asphyxiating gases, a formula has been given by Purser (2002) to estimate the time to reach incapacitation. In its simplest form, the FED is "the ratio of the exposure dose for a gaseous toxicant (or smoke) produced in a fire to that exposure dose statistically determined from independent data to produce an effect in 50% of subjects." For more information on the toxicity assessments, refer to Purser's research included in the SFPE Handbook (2002).

To facilitate modeling purposes and provide comparison of the fire species generations in this work, all productions have been converted to yields, which is the amount of products generated per unit of fuel mass. As fire species productions are dependent on the fire conditions as it develops, different yields are expected at different stages of fire. Using the unit of yield would also make the fire stage transitions more distinguishable (Chapter 0).

A brief introduction on the effects each fire species has on occupant escape is given below, as well as the equations used to convert each fire specie production into respective yields. Emphasis has been placed on soot yield conversions as it involves different measuring techniques and reporting styles.

## 4.1 Fire Species

The effect of each fire species on occupant escape abilities are outlined below. These effects, depending on their toxicity, amount produced and whether occurring simultaneously, can greatly influence the chances of a successful occupant escape.

### 4.1.1 Carbon Monoxide (CO)

Perhaps the most frequently encountered asphyxiant gas in fire is carbon monoxide, which has also been identified as the major cause of death (Babrauskas, 2008). It is always present in all fires to some extent due to incomplete combustion, especially in reduced ventilation conditions such as a room environment.

As carbon monoxide molecules bond with haemoglobin in the blood better than oxygen, it reduces oxygen supply to the body, especially the brain. This causes loss of consciousness as well as occupant escape capabilities to impair or even prevent a successful escape (Purser, 2002). A critical characteristic of asphyxia is the sudden onset whereby the effects of incapacitation rapidly become severe; such that escape becomes almost impossible once the victim is aware of the effects of fire. Furthermore, the first symptom of incapacitation appears to be on motivation. Therefore, the victims may tend to sleep rather than making an escape attempt, making the carbon monoxide the primary cause of death in fires (Purser and Berrill, 1983).

### 4.1.2 Carbon Dioxide ($CO_2$)

Although not an asphyxiant gas by itself, low concentration of oxygen (less than 15 percent) and very high concentrations of carbon dioxide (greater than 5 percent) can have similar asphyxiant effects (Purser, 1984).

The presence of carbon dioxide also stimulates breathing, causing hyperventilation, dizziness, drowsiness, and unconsciousness, superimposed on the respiratory effects. In a toxic environment, a high $CO_2$ concentration would increase the uptake of asphyxiant gases and significantly reduce time to incapacitation (Purser 2002).

### 4.1.3 Soot

The term smoke is defined by Mulholland (2002) as “the smoke aerosol or condensed phase component of the product of combustion”. In simpler terms, it is the solid carbon particles present in smoke (Glassman, 1986). It is a product of pyrolysis, generally formed in the fuel-rich regions of the flame. The soot particles grow in size “through gas-solid reactions, followed by oxidation (burnout) to produce gaseous products, such as CO and $CO_2$” (Tewarson, 2002). It can be measured in terms of its mass and particle size distribution. However, the primary properties of interest to the fire community are light extinction, visibility, and detection (Mulholland, 2002). Therefore, it is most often reported as optical obscuration or optical density.

Smoke emission is one of the critical items characterising a design fire, affecting visibility during escape and changes in human behaviour. The presence of a thick smoke not only significantly reduces escape speed, it also induces emotional stresses. This is especially evident in an irritant smoke (Jin, 2002) and affects occupant escape speeds. Design information to model occupant escape behaviours in smoke can be found from Jin’s research in the SFPE Handbook (2002).

### 4.1.4 Heat Released in Fires

The amount of heat produced is the most fundamental characteristic of any fire (Babrauskas and Peacock, 1992). Under sufficiently high radiation attack or upon inhaling the hot smoke, the heat can burn the respiratory tracts and exposed skin, causing serious pain and injury, which can eventually lead to death. An alternative expression for the amount of energy released is the heat of combustion, which is the heat released by a material, normalised by its mass loss. Heat of combustion is commonly used in modeling and fire risk assessments to predict the amount of heat contribution from a particular fuel.

The quantity of interest to the fire engineering industry is the effective heat of combustion. It can be determined theoretically or experimentally. In reality, the effective heat of combustion is not a constant for most real fuels; therefore, experimental evaluation is normally required. Figure 4.1 below shows a 17 mm sample of Western red cedar (Babrauskas, 2002). The effective heat of combustion quickly reached a steady state effective heat of combustion at roughly 12 MJ/kg, but increased to more than 30 MJ/kg near the end of test.

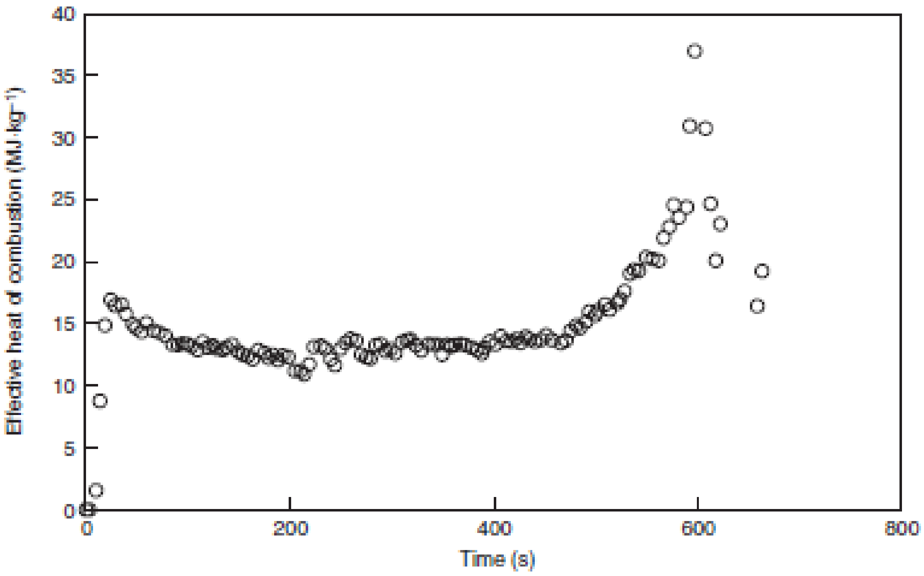



**Figure 4.1 Effective Heat of Combustion for 17mm Western cedar (Reproduced from Babrauskas, 2002)**

## 4.2 Fire Species Yields

A variety of reporting units have been used as fire engineering advances, both in terms of knowledge and experimental techniques. Therefore, a number of equations are introduced in this section to explain the derivation of various fire species yields, particularly soot yield calculations.

### 4.2.1 Gaseous Species Yield Conversions

Yields are used instead of productions or rates of production as it eliminates many factors that may affect the way items are burnt. The unit of yield (mass of product produced from a unit mass of fuel, in kg/kg) allows comparisons between experiments of different scales and configurations to be made. It can be simply defined by Equation 4.1 as:

$$y_i = \frac{m_i}{m_f} \qquad \text{Equation 4.1}$$

Where

| | | | |
|---|---|---|---|
| $y_i$ | = | yield of species i | (kg/kg or -) |
| $m_i$ | = | mass of species i generated | (kg or kg/s) |
| $m_f$ | = | mass of the gaseous fuel supplied | (kg or kg/s) |

Fire severity and factors that affect fire spread such as fuel arrangements and fabric barrier effects are collectively reflected by the mass loss rate. Once fire species productions are normalized by the mass loss rate, the yield would then reflect the effects of ventilation have on the species generation per unit of mass lost. For example, under vitiated conditions, CO production would rapidly increase due to incomplete combustion, accompanied by reduced $CO_2$ production.

As combustion does not remain constant throughout the entire testing timeframe, it should be expected that the yields would deviate more or less from the overall (or average) yield value as would be calculated from the equation above. To obtain the instantaneous yield from time series results, Gottuk and Lattimer's (2002) yield calculation (Equation 4.2) has been used:

$$y_i = \frac{(\dot{m}_f + \dot{m}_a) \times \chi_i \times \frac{M_i}{M_a}}{\dot{m}_f} \qquad \text{Equation 4.2}$$

Since the mass flow rate through the calorimeter's exhaust duct ($\dot{m}_{duct}$) includes both vaporised fuel ($\dot{m}_f$) and entrained air ($\dot{m}_a$), the equation can be simplified to:

$$y_i = \frac{\dot{m}_{duct} \times \chi_i \times \frac{M_i}{M_a}}{\dot{m}_f} \qquad \text{Equation 4.3}$$

Where

| | | | |
|---|---|---|---|
| $y_i$ | = | yield of species i | (kg/kg or -) |
| $\dot{m}_f$ | = | mass loss rate of fuel | (kg/s) |
| $\dot{m}_a$ | = | mass air entrainment rate | (kg/s) |
| $\dot{m}_{duct}$ | = | mass flow through the duct | (kg/s) |
| $\chi_i$ | = | mole fraction of species i | (-) |
| $M_i$ | = | molecular weight of species i, see Table 4.1 | (g/mol) |
| $M_a$ | = | molecular weight of incoming and exhaust air | (29g/mol) |

**Table 4.1 Molecular weights for common fire gases (Adapted from Loss, 2003)**

| Gas | Molecular Weight (g/mol) |
|---|---|
| Carbon Monoxide (CO) | 28 |
| Carbon Dioxide ($CO_2$) | 44 |
| Water Vapour ($H_2O$) | 18 |
| Hydrogen Bromide (HBr) | 81 |
| Hydrogen Chloride (HCl) | 36 |
| Hydrogen Cyanide (HCN) | 27 |

Mass flow through the duct (kg/s), mole fraction of species i (-), and mass record (kg) (or mass loss rate (kg/s), only if mass records are not available) are all required in time series for yield analysis to proceed and produce results in a time series.

As will be seen from subsequent chapters, fire species yields do not remain as a constant value throughout the entire combustion process. This is especially so for CO yields, which may be one or even two magnitudes higher as the fire progressed from the early growth stage to the final smouldering stage (Chapter 0).

### 4.2.2 Soot Yield Conversions

As the primary concern of a smoke is its obscurity, soot productions are commonly estimated using the smoke extinction area (SEA, $m^2/kg$) or the extinction coefficient ($m^{-1}$) by the Equations 4.4 and 4.5, both using light attenuation techniques described below.

#### 4.2.2.1 Light Attenuation Measurements in the Cone Calorimeter

By definition, attenuation (in some contexts also called extinction) is the gradual loss in intensity or strength of any kind of signal through a medium. In smoke measurements, this is typically done by using a helium-neon laser as the light source as shown in Figure 4.2 for a laser photometer fitted to the cone calorimeter. The laser signal passes through two beam splitters, one of which reaches the compensation detector without passing through the smoke. This is used as the reference to remove any fluctuations in the laser signal output. At the same time the other laser signal, attenuated by the smoke, is detected by the main detector at the other side of the duct. Smoke obscuration is then derived by comparing the attenuated signal against the reference signal.

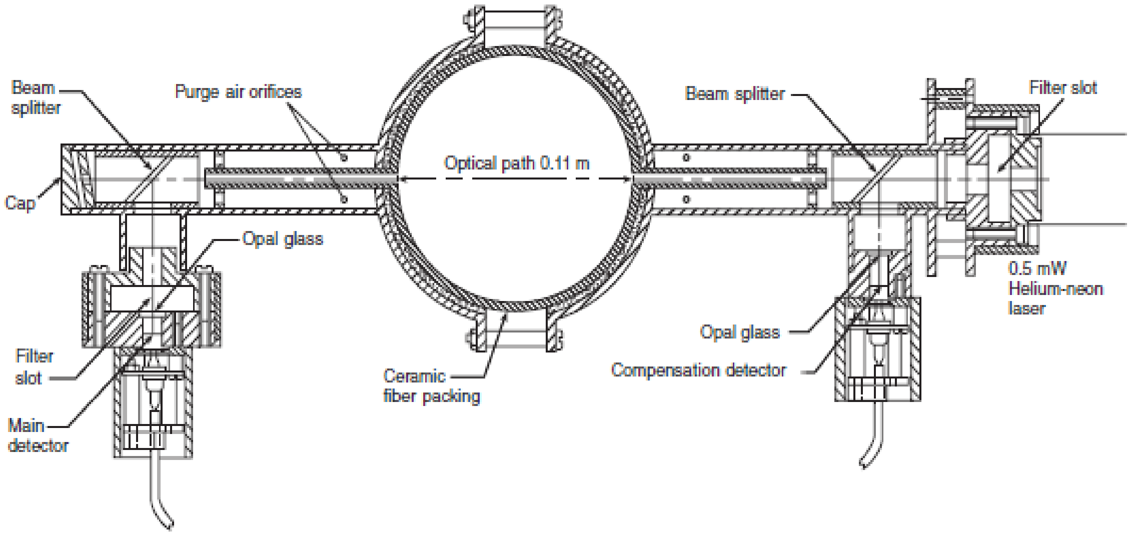



**Figure 4.2 Laser Photometer for measuring light attenuation (Reproduced from Babrauskas, 2002)**

It is worth noting that other than the more common units of $m^2/kg$ and $m^{-1}$ for the SEA and extinction coefficient methods, Initial Fires database (Särdqvist, 1993) has used "S" (unit of $obm^3/s$) as a measurement of optical density. This measurement, unfortunately, could not be converted into soot yield without knowing its mass loss rate, which was unavailable through the Initial Fires database. More information on this smoke measurement unit and Initial Fires database can be found in section 4.2.2.4 below and section 2.6, respectively.

### 4.2.2.2 Specific Extinction Coefficient

To convert soot yield from the smoke extinction area, the specific extinction coefficient ($m^2/kg$) is used to divide the specific extinction area.

$$y_s = \frac{SEA}{K_m} \qquad \text{Equation 4.4}$$

Where

| | | | |
|---|---|---|---|
| $y_s$ | = | the soot yield | (kg/kg or -) |
| $SEA$ | = | the specific extinction area | ($m^2/kg$) |
| $K_m$ | = | specific extinction coefficient | ($m^2/kg$) |

Various values have been proposed for the specific extinction coefficient, based on the types of materials burned and the sensitivity of the soot particulate detector at that time. For example, specific extinction coefficients of 7,600 $m^2$/kg and 4,400 $m^2$/kg reported by Seader and Einhorn (1976) were adopted in the CBUF research program. These values were derived from assorted wood and plastic specimens under flaming combustion and wood specimens under non-flaming combustion, respectively for soot yield estimation. On the hand, for turbulent diffusion flame for ethane, and value of 8,790 $m^2$/kg was proposed (Mulholland and Choi, 1998). Values between 9,000 and 10,000 $m^2$/kg have also been recommended for flaming fires by Babrauskas and Mulholland (1987).

#### 4.2.2.3 Extinction Coefficient

Alternatively, when smoke production is reported as an extinction coefficient, the yield of smoke is defined here as "the smoke aerosol or condensed phase component of the products of combustion" (Mulholland, 2002). This definition differs from the American Society for Testing and Materials (ASTM) (ASTM E1995, 2009) definition of smoke, which includes the evolved gases. The equation below was created to calculate soot yield, based on light extinction measurements made with a helium-neon laser (Mulholland at al., 2000).

$$y_s = \frac{C_s \dot{V} K}{\sigma_s \dot{m}_f} \qquad \text{Equation 4.5}$$

Where

| | | | |
|---|---|---|---|
| $y_s$ | = | the yield of smoke | (kg/kg or -) |
| $C_s$ | = | the smoke profile factor (Mulholland et al. (2000) takes this to be 0.97) | (-) |
| $\dot{V}$ | = | the exhaust flow rate | ($m^3$/s) |
| $K$ | = | the extinction coefficient | ($m^{-1}$) |
| $\sigma_s$ | = | the specific extinction area (taken to be 8,700 $m^2$/kg) | ($m^2$/kg) |
| $\dot{m}_f$ | = | the mass loss rate of fuel | (kg/s) |

Both the Specific Extinction Coefficient method (section 4.2.2.2) and the Extinction Coefficient method (section 4.2.2.3) have their own advantages and disadvantages. The first method is undoubtedly more convenient, requiring only one variable. However, it should be noted that literature has suggested values ranging from 4,400 $m^2$/kg for non-flaming fires to almost 10,000 $m^2$/kg for flaming fires. Conversely in the extinction coefficient method, Mulholland and Croarkin (2000) had used an estimated mean specific extinction area of 8,700 $m^2$/kg. It was an averaged specific extinction coefficient across seven different laboratories, for 29 different fuel types ranging from heptane to oak to polystyrene, for a range of test scales (Mulholland and Croarkin, 2000). The maximum average specific extinction coefficient was 11,600 $m^2$/kg for fuel oil, while the minimum average specific extinction coefficient was 5,300 $m^2$/kg for acetylene. The expanded uncertainty (95% confidence interval) for the estimate mean specific extinction coefficient was 1,100 $m^2$/kg from 29 different fuel types.

An accurate conversion from smoke obscuration to soot yield is important as it allows the determination of the smoke mass concentration for design purposes, as well as "validating computational models for smoke flow and dispersion in buildings" (Mulholland and Croarkin, 2000). It would also facilitate a convenient soot yield conversion from different smoke production measurements. Nonetheless, one should always be aware of the sources of these values and the standard deviations associated with these values.

To serve the purpose of consistent soot yield comparisons, the value 7,600 $m^2$/kg will be used in this research as the specific extinction coefficient for calculating soot yield from specific extinction areas (SEA). It is also the more conservative estimate for flaming fires of all conversion factors, and will be used until it can be decided which value is the more appropriate conversion factor.

### 4.2.2.4 Smoke Production

During the infancy of fire research, fire tests were being performed independently in small notional groups, with their own definitions for smoke. Consequently, smoke measurements were reported as smoke production, “S” in the Initial Fires research (Särdqvist, 1993), in unit of obm$^3$/s. This unit is a measure of optical density that is derived from:

$$S = POD \times \dot{m} \times X \qquad \text{Equation 4.6}$$

Where

| | | | |
|---|---|---|---|
| $POD$ | = | Particulate optical density, 33,000 in flaming mode and 19,000 in non-flaming mode | (obm$^3$/kg) |
| $\dot{m}$ | = | Mass loss rate | (kg/s) |
| $X$ | = | Fraction of mass loss rate that is converted into obscuring particles (equivalent to soot yield) | (-) |

This unit can then be converted smoke potential, specific extinction coefficients, and even directly as soot yields, if mass loss rates were available. Unfortunately this was not the case; hence the extensive research results from Initial Fires (1993) could not be used for distribution fitting in this research.

### 4.2.3 Heat of Combustion Conversion

The heat released from any fire test is the most important quantity, and must be determined accurately to ensure adequate safety in designs. The theory of oxygen consumption calorimetry was first developed and published by Parker (1977) and Huggett (1980) to more accurately measure the heat released by a burning material. Central to this theory is the fact that in addition to the release of heat, the combustion process consumes oxygen. Hence, by measuring the rate oxygen is consumed, the rate at which heat is being generated could be derived. Huggett concluded that the assumption of constant heat release rate per unit mass of oxygen consumed would be sufficiently accurate for most fires to ±5 %. The constant value of 13.1 MJ/kg was recommended (Huggett, 1980). This meaning that the heat release rate of materials could be closely estimated by capturing all of the products of combustion in an exhaust hood and measuring the flow rate of oxygen in that exhaust flow. To determine the amount of energy available from burning a unit mass of fuel, the energy released is divided by the rate of mass loss.

It should be noted that the heat of combustion derived from oxygen consumption theory produces the effective heat of combustion, instead of the net heat of combustion, as combustion is never completely efficient in natural fires, even under unrestricted ventilation (Drysdale, 2002).

# 5 Yield Calculations

Standardised sample preparations and experimental procedures are important issues to consider when making comparisons against other test results. This establishes an international consensus on terminology to ensure a sound basis for meaningful comparisons as well as easier technology transfer across different countries. In the same manner, the units used to report and document the test results should also be standardised, using similar data processing procedures.

In this research, the unit of yield (kg/kg or MJ/kg) is used for analysis to produce the final recommendation. Restating Equation 4.1 below, yield is simply defined as:

$$y_i = \frac{m_i}{m_f} \qquad \text{Equation 5.1}$$

Where

| | | | |
|---|---|---|---|
| $\boldsymbol{y_i}$ | = | **yield of species i** | **(kg/kg or -)** |
| $\boldsymbol{m_i}$ | = | **mass of species i generated** | **(kg or kg/s)** |
| $\boldsymbol{m_f}$ | = | **mass of the gaseous fuel supplied** | **(kg or kg/s)** |

Influences from factors such as fuel configuration, and fire growth rates are reflected in the mass loss rate, which is used to normalise the species production. In this way, all factors that affect the way items burn will be removed, given the ventilation conditions remain the same. At the same time, should these time-dependent variables become significant in fire scenarios modelling or analysis at any point, it can be inferred from the mass loss profile.

This unit of yield has become increasingly adopted for modelling purposes. Simulation models such as for BRANZFIRE, FDS and CFAST process inputs in terms of yields in modelling tenability conditions and designing escape paths (Wade, 2004; Fire Dynamics Simulator, User's Guide, 2010; CFAST, User's

Guide, 2008). Therefore, all results presented in this research are given as yields to suit both the purposes of convenient comparison and modelling requirements.

## 5.1 Mass Loss Rate Calculation

Due to inherent instrumental fluctuation and external influences, such as the convection during combustion, exerting upward and downward forces on the fuel and the mass scale, negative yields could occur if mass loss rates were not smoothed prior to use. To minimise the occurrence of unrealistically high (or low) yields in the analysis, a smoothing procedure on the mass records was necessary. The simple three-step procedure below was carried out for each test to smooth the mass records and calculate the mass loss rate, prior to applying the mass loss rate threshold for yield calculations:

1. A preliminary 5-point moving average was carried out on the mass record to reduce any fluctuations in the reading

2. Then mass loss rate was calculated using the gradient calculation by taking the smoothed mass reading 15s before and after the time of interest and calculate the rate of change over the 30s period

3. Finally, another 5-point moving average was done on the mass loss rate to further reduce the occurrence of unrealistic yields that may alter the final distribution

This was applied to all tests included in this research database, except for NIST's FASTData tests, where records for mass flow rate through the exhaust duct are not available.

After mass loss rates were calculated, it was necessary to define the beginning and end of tests using a consistent criterion.

## 5.2 Beginning and End of Test Definitions

To derive a meaningful species yield, only segments of the test that are considered to be "effectively burning" will be used for the final distribution fitting. Several criteria have been considered to define such condition, including the heat release rate, percentiles of the total mass lost, and the minimum mass loss rate threshold. After a few result comparisons, the minimum mass loss rate threshold was chosen as the criteria to distinguish whether the item is in an effective combustion where a minimum amount of mass is being converted to heat and combustion products.

Three end of tests criteria for cone calorimeter tests are given in ISO 5660 (1993), of which, the minimum mass loss rate threshold criterion has been applied to all the cone calorimeter tests to define the start of test. However, unlike cone calorimeter samples with similar sample sizes and masses, furniture calorimeter samples can vary significantly in sample size. Consequently, several criteria (discussed below) have been considered in defining the beginning and end of test for furniture calorimeter tests results.

### 5.2.1 The Heat Release Rate Criterion

Previous work by CBUF and Enright has defined the beginning of test ($t = 0$) when the heat release rate reached 50kW (Sundström, 1995; Enright, 1999). This value was chosen to signify when the items began to burn under their own growth rate, and not from the 30 kW burner used in CBUF research program. Alternative values such as 30 kW (Ahrens, 2007) and 25 kW (Bukowski, 1995 and Ristic, 2001) have also been suggested by other researchers. The amount of combustible mass involved in the test should also be considered when using a definitive threshold. This can be illustrated by comparing a 20kW fire from a trash container filled with newspapers only and a 20kW fire from a queen-sized mattress. Consequently, the threshold should be adjusted to accommodate different samples sizes.

Depending on ignition duration, the burner may still be involved when the heat release rate exceeds the specified limit. Although the heat release from the burner can be easily removed from the record, little research has been done to determine species production from these ignition sources. Therefore, species yields could be over-estimated to include the burner contribution during the beginning of the test.

### 5.2.2 The Percentile Criterion based on Mass Loss

Even though the burner contribution may be insignificant, it did not seem to be the most suitable criteria for this research, which further converts species production into yields using the mass loss rate of the fuel. Naturally, criteria set upon mass loss during the experiment were preferred over the commonly used heat release rate criteria, since it was to be used as the normalising quantity to calculate species yields.

Initially a percentile criterion was explored, discarding the first and last 10% of the total mass loss, and only using the middle 80% of the test record. For example, for a chair that has lost 20kg of its mass during the test, beginning and end of test would be defined as when the chair has lost 2kg and 18kg of its mass, respectively. However, this criterion was not deemed adequate since the total mass loss does not directly reflect the combustion status.

### 5.2.3 The Percentile Criterion based on Mass Loss Rate

The same concept was applied to the mass loss rate, which is a better representation of the combustion. Under this criterion, only test results where the corresponding mass loss rate falls between the $10^{th}$ and $90^{th}$ percentile of the mass loss rate were considered. Unfortunately, extremely high or low mass loss rates occur due to factors such as instrumentation, mass fluctuation caused by external factors (for example, draft). This criterion was also deemed inadequate as it could not give a consistent criterion to define the beginning and end of test.

### 5.2.4 The Mass Loss Rate Threshold Criterion

Following the ISO and ASTM standards specifying the end of test for a cone calorimeter test using a constant mass loss rate value (150 g/m$^2$ being lost during any 1 min) (ISO 5660-1, 2002; ASTM E1354-10, 2010), it seemed more reasonable to define the beginning and end of tests using a mass loss rate threshold. This indicates the item's actual burning, releasing heat and other species from the item of interest as it combusts, while giving consistency in the definition.

Mass loss rate threshold derivations are discussed in the section below. It should be noted that the final threshold value was sufficient to exclude the period of burner involvement. Furthermore, burning rate should not be confused with mass loss rate (fuel supplied), since not all fuel supplied would be burned. Nonetheless, for items burning with unlimited air supply (i.e. free burning), these two terms are essentially identical (Karlsson and Quintiere, 2000).

## 5.3 The Mass Loss Rate Threshold

The mass loss rate threshold was necessary to prevent very small mass loss rates being included into the analysis, as this would generate unrealistic yield values that are not physical explainable. The small mass loss rates occur due to fluctuations in the mass readings, which are caused by the convection induced during combustion. Alternatively, the mass loss rate threshold should not too high to remove a significant data portion to affect the final analysis outcome.

A mass loss rate threshold of 0.001 kg/s was initially trialled. It was selected to avoid removing too much data. Distributions are presented as histograms with the vertical axis representing the frequency count of the yield values on the horizontal axis. As can be seen from the histogram in Figure 5.1 for a distribution subset (Enright's polyurethane foam collection), a significant portion of the $CO_2$ yield has exceeded the stoichiometric $CO_2$ yield of 2.1 g/g for flexible polyurethane foams (Karlsson and Quintiere, 2000).

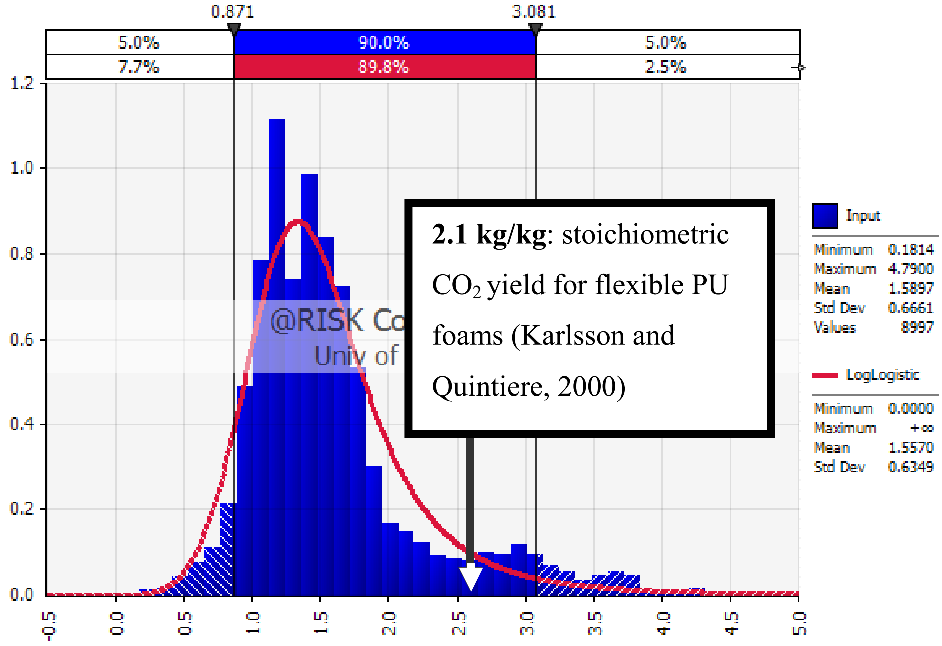



**Figure 5.1** **Fitted Distribution Profile for Enright's Polyurethane Foam Tests on $yCO_2$ Mass Loss Threshold of 0.001 kg/s (Adapted from Enright, 1999)**

To demonstrate the effects of applying different minimum mass loss rate limits, Enright's A1S1 test results are shown below for a polyester and blended fabric covered polyurethane foam single seater. The heat release rate and mass loss profiles as shown in Figure 5.2.

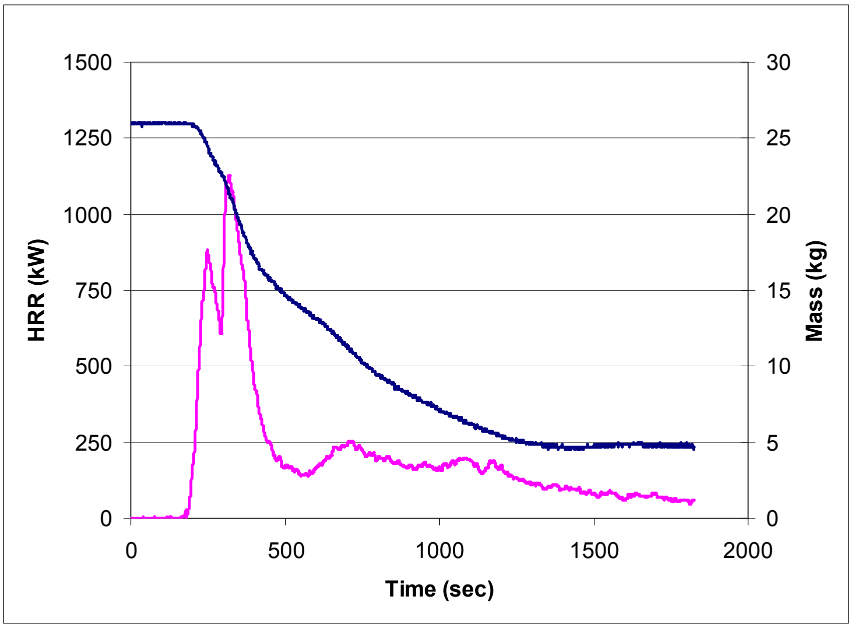



**Figure 5.2** **Mass and Heat Release Rate Profiles for a Polyester and Blended Fabric covered Polyurethane Foam Single Seater (no interliner) (test "A1S1") (Redrawn from Enright, 1999)**

A range of mass loss rate thresholds were trialled to determine the most suitable value for the final analysis. Two mass loss rate limits – 0.001 kg/s and 0.005 kg/s are shown below in Figure 5.3 to Figure 5.5. The effects of an increased mass loss rate threshold are most noticeable towards the end of the test, where burning rates are much reduced during smouldering combustion with the primary fuel being the timber frame.

Very high yields have been observed towards the end of test when using the lower threshold. A segment of test around 1500s has been excluded where as the mass loss rate temporarily fell below 0.001 kg/s. Hence, it can be concluded that the high yields are most likely caused by magnification due to division by a small mass loss rate value, and not actual species yields. Consequently, these unrealistic values were removed by raising the mass loss rate threshold to prevent creating unrealistic yield distribution profiles.

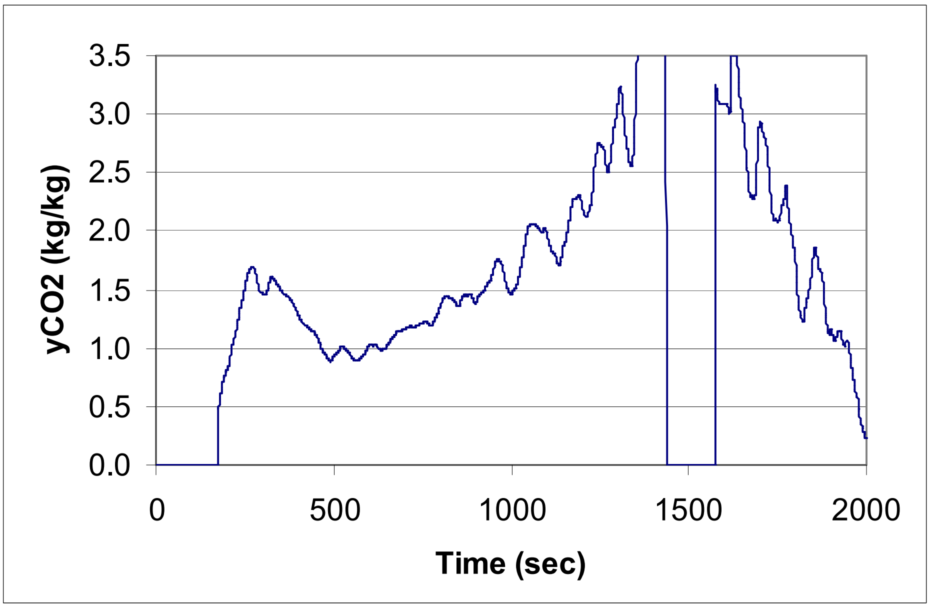



**Figure 5.3** **$CO_2$ Yield Profile for a Polyester and Blended Fabric covered Polyurethane Foam Single Seater (test "A1S1")**
**a) Mass Loss Rate Threshold of 0.001 kg/s**
**(Adapted from Enright, 1999)**

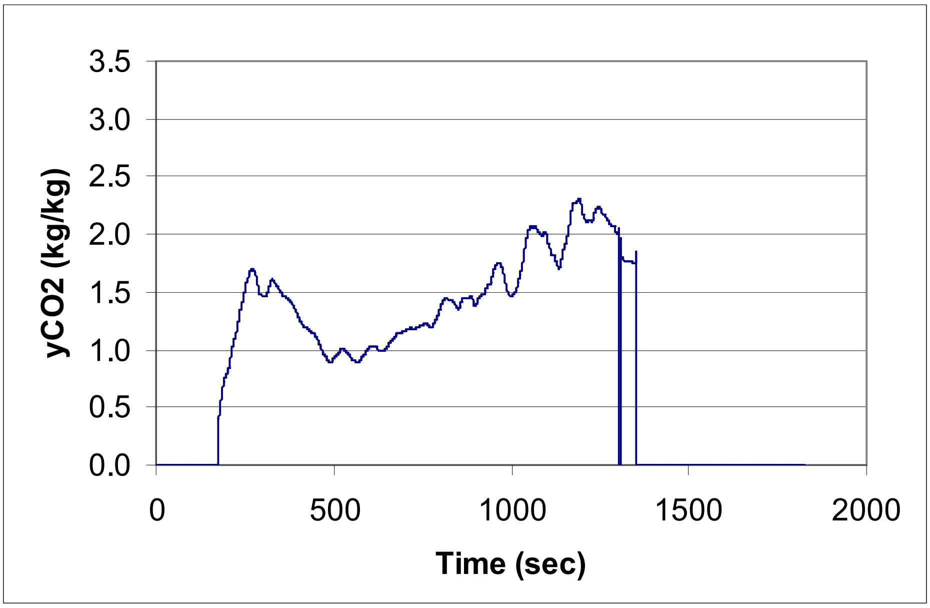



**Figure 5.3** **$CO_2$ Yield Profile for a Polyester and Blended Fabric covered Polyurethane Foam Single Seater (test "A1S1")**
**b) Mass Loss Rate Threshold of 0.005 kg/s**
**(Adapted from Enright, 1999)**

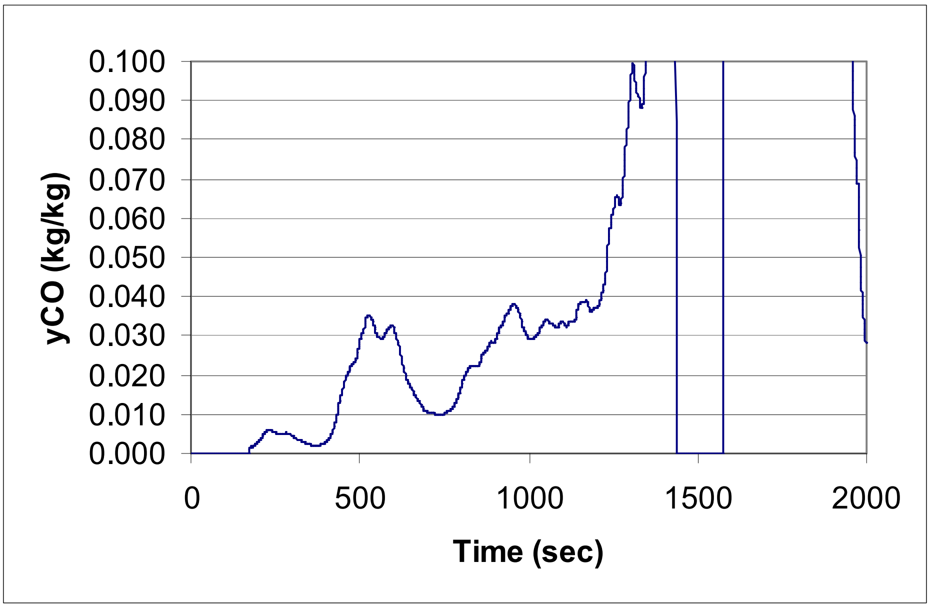



**Figure 5.4 CO Yield Profile for a Polyester and Blended Fabric covered Polyurethane Foam Single Seater (test "A1S1")**
**b) Mass Loss Rate Threshold of 0.001 kg/s**
**(Adapted from Enright, 1999)**

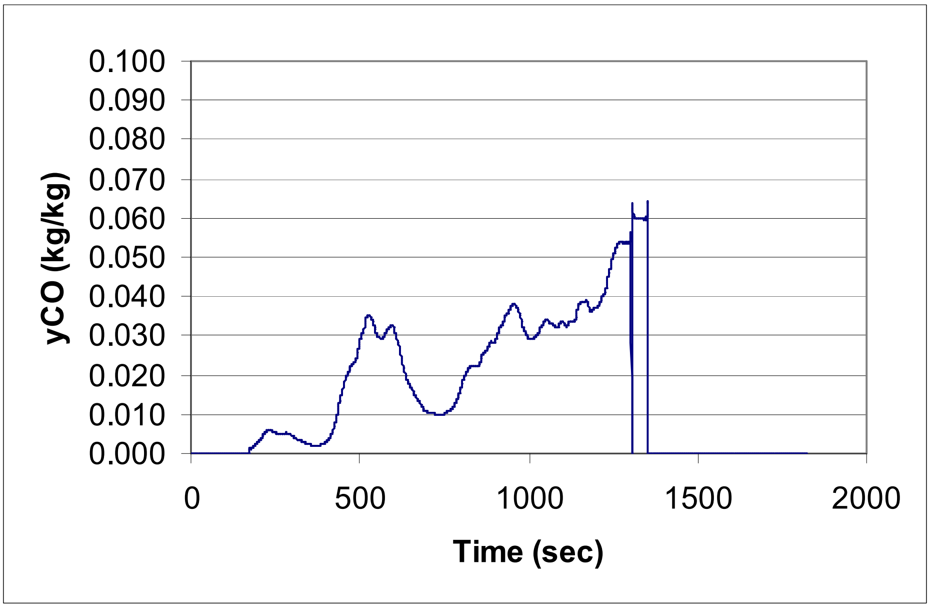



**Figure 5.4 CO Yield Profile for a Polyester and Blended Fabric covered Polyurethane Foam Single Seater (test "A1S1")**
**b) Mass Loss Rate Threshold of 0.005 kg/s**
**(Adapted from Enright, 1999)**

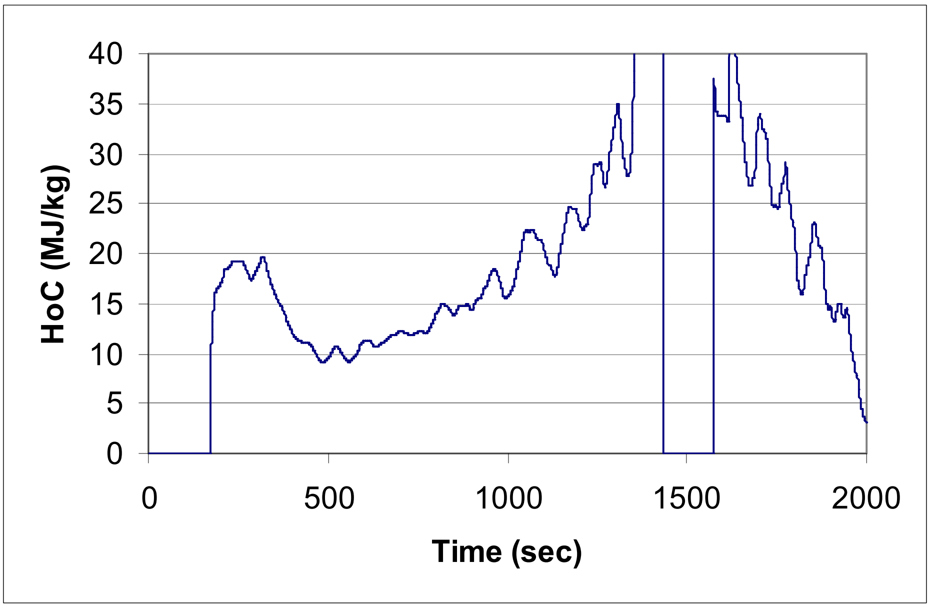



**Figure 5.5** Heat of Combustion Profile for a Polyester and Blended Fabric covered Polyurethane Foam Single Seater (test "A1S1")
a) Mass Loss Rate Threshold of 0.001 kg/s
(Adapted from Enright, 1999)

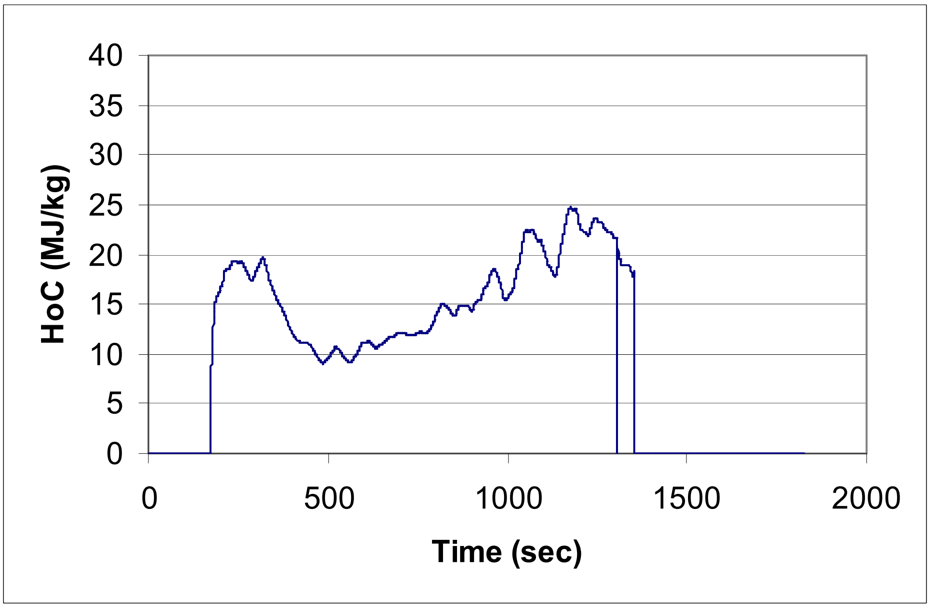



**Figure 5.5** Heat of Combustion Profile for a Polyester and Blended Fabric covered Polyurethane Foam Single Seater (test "A1S1")
b) Mass Loss Rate Threshold of 0.005 kg/s
(Adapted from Enright, 1999)

Figure 5.6 shows the maximum (dotted line) and average (solid line) $CO_2$ yields under different mass loss rate thresholds. Corresponding CO yields and heat of combustions are shown in Figure 5.7 and Figure 5.8.

Both the maximum and average dropped significantly to a plateau at approximately 0.005 kg/s, except for the maximum CO yield line. Although both maximum and average values continue to drop beyond the 0.005 kg/s threshold (as it would be if continuously increasing the mass loss rate threshold) the rate at which these yield values change is much less compared to the initial rapid decline. To achieve balance between avoiding excessively high and unrealistic yields and keeping as much as the original data, a final minimum mass loss rate of **0.005 kg/s** was chosen.

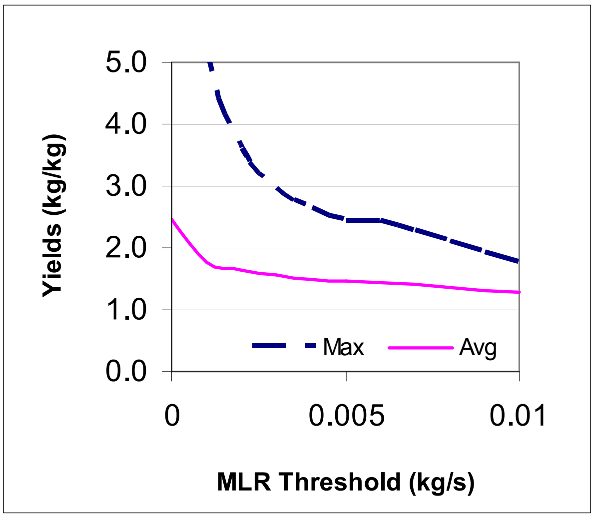



**Figure 5.6** **Mass loss rate threshold comparisons for item A1S1 (Maximum and Average $CO_2$ yields)**
**(Adapted from Enright, 1999)**

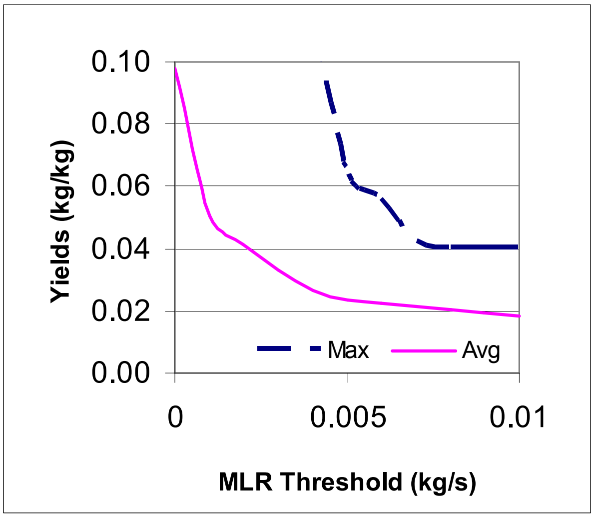



**Figure 5.7 Mass loss rate threshold comparisons for item A1S1 (Maximum and Average CO yields) (Adapted from Enright, 1999)**

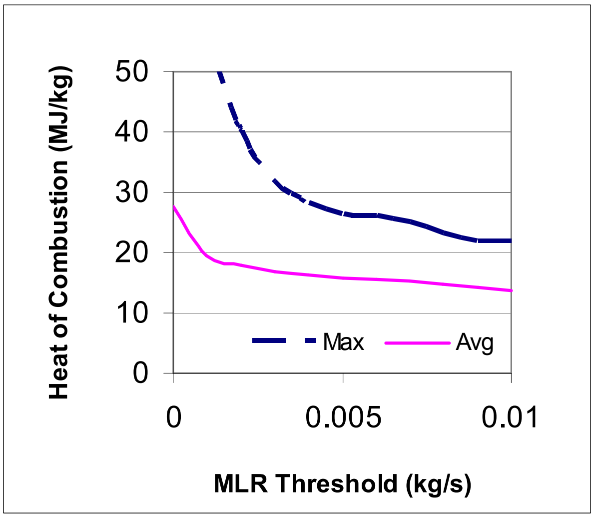



**Figure 5.8 Mass loss rate threshold comparisons for item A1S1 (Maximum and Average Heats of Combustion) (Adapted from Enright, 1999)**

As a result of much reduced maximum and average yields by increasing the mass loss rate threshold from 0.001 kg/s to 0.005 kg/s, the same dataset (Enright's polyurethane foam collection) had a much improved yield distribution, as shown in Figure 5.9.

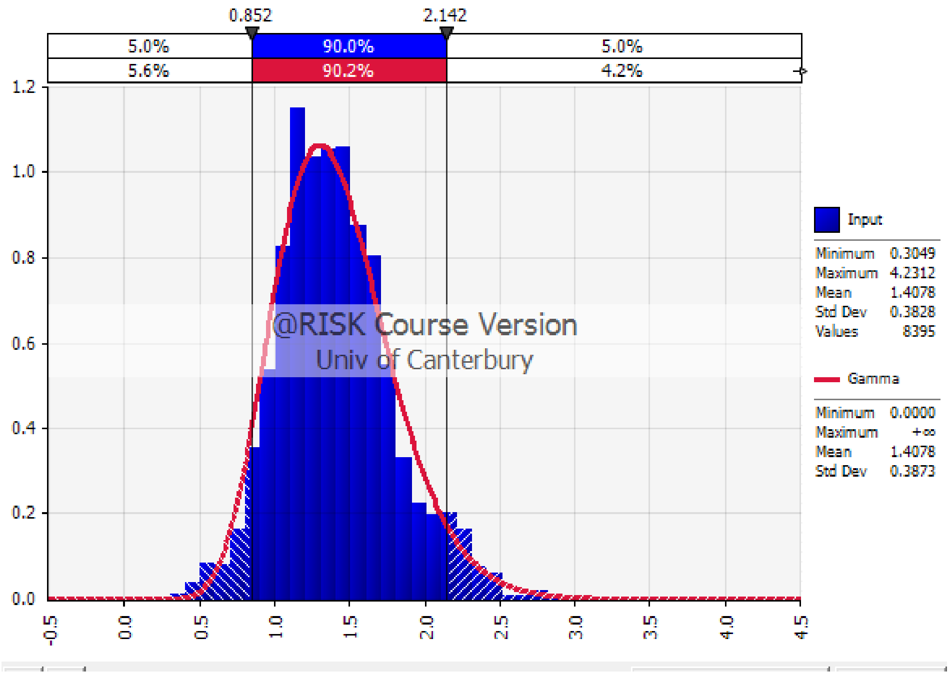



**Figure 5.9 Fitted Distribution Profile for Enright's Polyurethane Foam Tests on $yCO_2$ Mass Loss Threshold of 0.005 kg/s (Adapted from Enright, 1999)**

The final 0.005 kg/s threshold was derived from single seaters, which comprise the majority of the furniture calorimeter test. Other furniture calorimeter tests involving significantly different masses required a different mass loss rate threshold to produce consistent results. For example, a 0.005 kg/s mass loss rate for a 100kg foam sofa bed may be comparably insignificant, while it may represent rapid consumption of a 2 kg foam cushion. Consequently, since two-seater tests and beds have approximately twice as much mass as the single seaters, a modified mass loss rate threshold of 0.01 kg/s was used as the criterion to define beginning and end of tests. For Collier and Whiting's 2 kg purpose-built chairs (2008), the threshold was reduced to 0.001 kg/s as the masses involved are much smaller.

## 5.4 Moving Average Intervals

As the final step in yield calculations, the final species productions were divided by the smoothed mass loss rates. As the instantaneous yields still exhibited some fluctuations (Figure 5.10 a)), the instantaneous values were smoothed with moving averages to examine the underlying trend more closely and further remove some excessively high yields that only appear temporarily due to reading fluctuations or momentary changes in combustion dynamics. However, care was taken to avoid over doing by averaging over a long period, obscuring any stage transitions (if any) from the initial growth stage through the transition stage to the smouldering combustion stage. The stage distinctions are discussed in more depth in Chapter 0.

To examine the changes in yield profiles with and without the final moving average on yields, a single seater (A5S1) tested by Enright (1999) is considered below using 0.005 kg/s mass loss rate threshold for:

- instantaneous yields in Figure 5.10 a),
- moving averages over a timeframes of 30 seconds in Figure 5.10 b), and
- moving averages over a timeframes of 60 seconds in Figure 5.10 c)

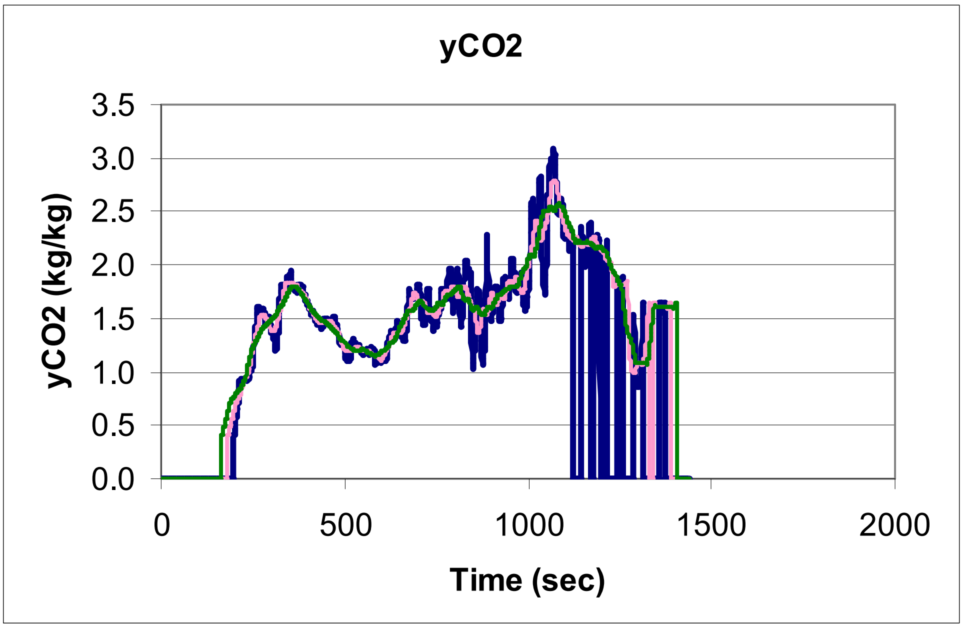



**Figure 5.10 $CO_2$ Yield Profile for a Polypropylene Fibre Fabric covered Polyurethane Foam Single Seater (test "A5S1")**
**(blue line – instantaneous, pink line – 30s moving avg, green line – 60s moving avg)**
**(Adapted from Enright, 1999)**

Seven other single seaters from Enright (1999) are also considered below to produce Table 5.1 below, comparing the average $CO_2$ yields for instantaneous yields, 30s-moving averaged yields, and 60s-moving averaged yields. It should be noted that the eight chairs are composed of polyurethane foam with different fabric combinations (Enright, 1999).

**Table 5.1 Average $CO_2$ Yields for Enright's Furniture Tests (0.005 kg/s MLR Threshold)**

| | Average Yields | | |
|---|---|---|---|
| **Test** | **Instantaneous** | **30s averaging interval** | **60s averaging interval** |
| **A1S1** | **1.46** | **1.46** | **1.46** |
| **A2S1** | **1.23** | **1.24** | **1.24** |
| **A3S1** | **1.30** | **1.29** | **1.29** |
| **A4S1** | **1.47** | **1.46** | **1.44** |
| **A5S1** | **1.63** | **1.63** | **1.62** |
| **B6S1** | **1.46** | **1.45** | **1.44** |
| **C7S1** | **1.45** | **1.38** | **1.34** |
| **D8S1** | **1.35** | **1.34** | **1.34** |

Graphically, Table 5.1 would transform into Figure 5.11 to demonstrate that the effects of the moving average does not cause the average values to deviate much from the instantaneous yields' average values. This can be seen from the three lines very closely follow one another. In particular, the 30s-moving averaged yields appear to superimpose on top of the instantaneous yields, demonstrating the 30-second moving average effects have minimal effects on the average yield values.

The point of significant deviation occurred at item C7S1. It is a polyurethane foam and nylon pile fabric combination where only less than 8kg of C7S1 material was combusted, compared to more than 20kg combusted in all other tests.

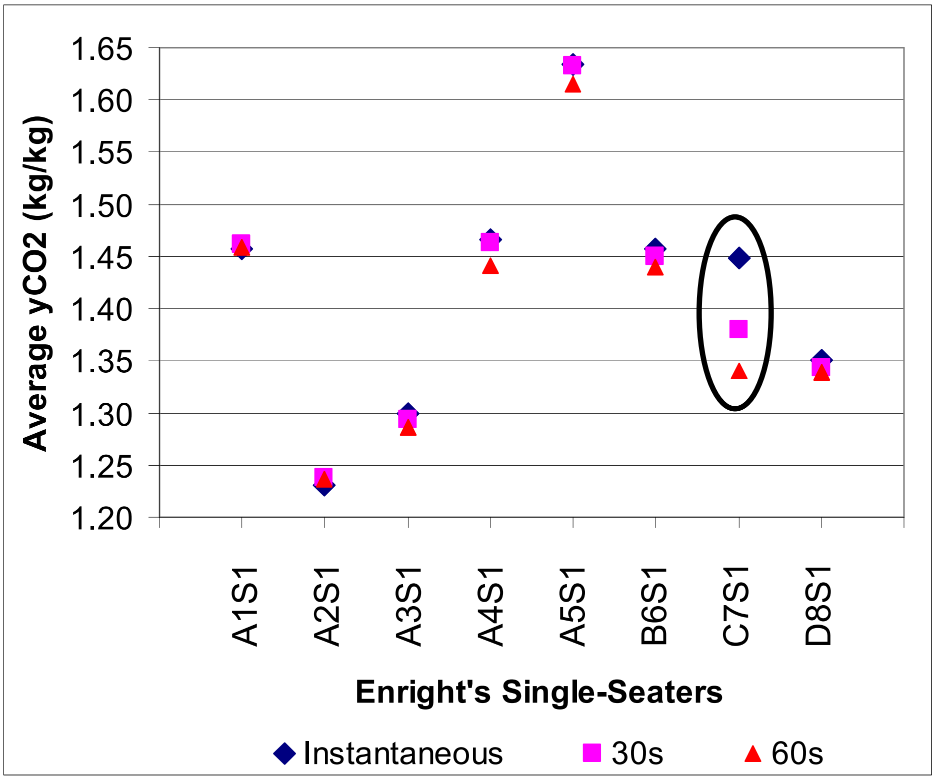



**Figure 5.11** **Average $CO_2$ Yields for Enright's Single Seaters (Adapted from Enright, 1999)**

Maximum $CO_2$ yield values are also examined in a similar manner. Greater deviations from the instantaneous values have become more evident as can be seen in Table 5.2 and Figure 5.12, as moving averages are expected to reduce extreme values. When comparing test A2S1, it can be seen that maximum $CO_2$ values (4.23 kg/kg) can sometimes be more than three times of its average value (1.23 – 1.24 kg/kg). This further confirms the necessity to report the spread in experimental value, ideally using a distribution function.

Table 5.2 **Maximum $CO_2$ Yields for Enright's Furniture Tests (0.005 kg/s MLR Threshold)**

| | Maximum Yields | | |
|---|---|---|---|
| **Test** | **Instantaneous** | **30s averaging interval** | **60s averaging interval** |
| A1S1 | 2.43 | 2.31 | 2.21 |
| A2S1 | 4.23 | 4.23 | 4.23 |
| A3S1 | 2.69 | 2.46 | 2.21 |
| A4S1 | 2.76 | 2.52 | 2.36 |
| A5S1 | 3.09 | 2.79 | 2.58 |
| B6S1 | 2.28 | 1.94 | 1.83 |
| C7S1 | 2.08 | 1.96 | 1.79 |
| D8S1 | 1.98 | 1.95 | 1.92 |

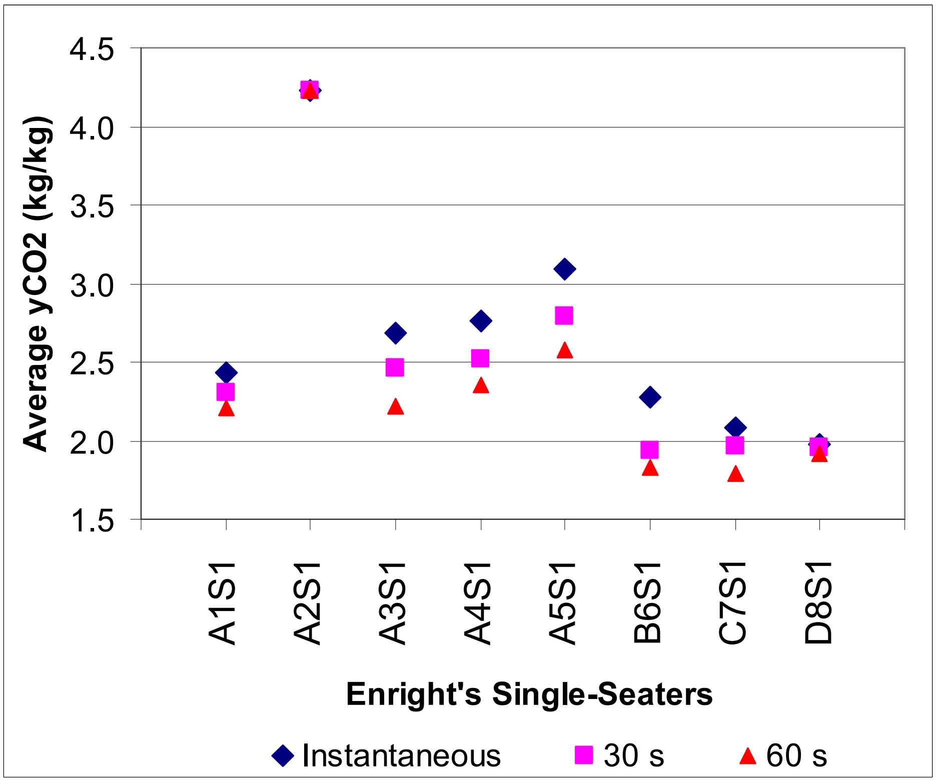



**Figure 5.12** **Maximum $CO_2$ Yields for Enright's Single Seaters (Adapted from Enright, 1999)**

Since Figure 5.12 has shown a 30s moving average is adequate to smooth the yield profiles (by reducing maximum values) while having minimal deviation from the instantaneous average as shown in Figure 5.11, it was decided that the 30s moving average yields was a reasonable approach and has been applied to all tests processed in this research for the final analysis. Although the 60 second moving average further reduces the maximum values in the tests, some cone calorimeter samples are quickly consumed within three minutes. Therefore, averaging over too long a period may obscure some burning characteristics of the samples.

The only dataset that did not have the moving average interval applied is NIST's FASTData 1.0 database (1999). Only species yields and mass records are available in time series, without the actual species production and mass flow rate through the exhaust duct hence preventing similar data reduction procedure to take place. Therefore, the yields reported by the FASTData database 1.0 have been used directly in the final distribution fitting. The only data processing was to convert the specific extinction coefficient into soot yield through a division of 7,600 $m^2/kg$ (Refer to section 4.2.2).

## 5.5 Stoichiometric Yields

Understanding that it is impossible to remove all fluctuations in measurements and control every aspect of the complex thermochemical reaction, it is important to recognise that physical limits do exist for every chemical reaction.

Stoichiometry is defined by Karlsson and Quintiere (2000) as a balanced chemical equation that gives the exact proportions of the reactants for complete conversion to products, where no reactants are remaining.

In order to identify the maximum possible yields for each fire species, their maximum theoretical yield, called $y_{i,max}$, based on stoichiometry must be calculated. These values were used as an indicator for the maximum possible yield value that should be used in any design calculations or modelling. Naturally, a variety of chemically complex materials are involved in the dataset collected. Nonetheless, the maximum possible $CO_2$ yield shall not exceed that of a pure carbon conversion to $CO_2$ as shown in Equation 5.2 below.

$$C + 2O_2 + 2H_2 \rightarrow CO_2 + 2H_2O \qquad \text{Equation 5.2}$$

Knowing that the molecular weights of C and $CO_2$ are 12g and 44g, respectively, the maximum $CO_2$ yield for all tests should not be higher than $\frac{44g}{12g} = 3.7g/g$. This value is supported by Karlsson and Quintiere (2000) in their maximum theoretical yield calculations based on stoichiometry, where no $CO_2$ yield exceeds 3.7 kg/kg as shown in Table 5.3 below.

**Table 5.3 Maximum theoretical yields based on stoichiometry (Reproduced from Karlsson and Quintiere, 2000)**

| Fuel | Stoich. fuel/ox Ratio, *r* | $y_{CO,max}$ (g/g) | $y_{CO_2,max}$ (g/g) | $y_{O_2,max}$ (g/g) |
|---|---|---|---|---|
| Propane | 0.276 | 1.91 | 3.00 | 3.64 |
| Acetylene | 0.325 | 2.15 | 3.39 | 3.69 |
| Ethanol (ethyl alcohol) | 0.480 | 1.22 | 1.91 | 2.09 |
| Heptane | 0.284 | 1.96 | 3.08 | 3.52 |
| Polystyrene | 0.325 | 2.15 | 3.38 | 3.08 |
| Nylon | 0.428 | 1.48 | 2.32 | 2.61 |
| Polyurethane (flexible) PU | 0.580 | 1.41 | 2.21 | 2.05 |
| Polymethyl methacrylate | 0.521 | 1.4 | 2.2 | 1.92 |
| Wood (pine) | 0.601 | 0.89 | 1.40 | 1.13 |
| Polyvinyl chloride (PVC) | 0.710 | 0.903 | 1.42 | 1.42 |

A more realistic limit can be found from the "unlimited air yield of species", denoted as $y_{i,WV}$ (Karlsson and Quintiere, 2000). It is the species yield under unlimited air supply (i.e. free burning) shown in Table 5.4, which is determined experimentally as it depends on the fuel and the burning configuration. These yields are expected to be lower than its corresponding maximum theoretical yield (based on stoichiometry) as the fuel is not all converted to one single product. It is especially true when comparing $y_{CO,max}$ (1.41 g/g) and $y_{CO,Wv}$ (0.031 g/g) for polyurethane, this is because it is impossible to convert all products into CO as $CO_2$ will always be produced in all combustions.

**Table 5.4 Unlimited air yield of species**
**(Reproduced from Karlsson and Quintiere, 2000)**

| | Well-ventilated (WV) fires ($\phi < 1$) | | | | | | |
|---|---|---|---|---|---|---|---|
| **Fuels** | $y_{CO_2}$ (g/g) | $y_{CO}$ (g/g) | $y_s$ (g/g) | $\Delta_{H_{eff}}$ (kJ/g) | $\Delta_{H_c}$ (kJ/g) | $D_m$ (m²/g) | $y_{HCl}$ (g/g) |
| Propane | 2.85 | 0.005 | 0.024 | 74 | 76.4 | 0.16 | NA |
| Acetylene | 2.6 | 0.042 | 0.096 | 37 | 48.2 | 0.32 | NA |
| Ethanol (ethyl alcohol) | 1.77 | 0.001 | 0.008 | 26 | 26.8 | NA | NA |
| Heptane | 2.85 | 0.01 | 0.037 | 41 | 44.6 | 0.19 | NA |
| Polystyrene | 2.3 | 0.06 | 0.16 | 27 | 39.2 | 0.34 | NA |
| Nylon | 2.06 | 0.038 | 0.075 | 27 | 30.8 | 0.23 | NA |
| Polyurethane (flexible) PU | 1.5 | 0.031 | 0.23 | 19 | 27.2 | 0.33 | NA |
| Polymethyl methacrylate | 2.1 | 0.01 | 0.022 | 24 | 25.2 | 0.109 | NA |
| Wood | 1.33 | 0.005 | 0.015 | 12 | 17.7 | 0.037 | NA |
| Polyvinyl chloride (PVC) | 0.46 | 0.063 | 0.14 | 5.4 | 16.4 | 0.40 | 0.5 |

*Notes:* NA = not applicable; — = not measured.

The values reported by Karlsson and Quintiere (2000) are average values only. Therefore, the maximum $CO_2$ yield adopted should be higher than the one reported by Karlsson and Quintiere if it were to be used as the maximum bound for realistic $CO_2$ yields. As a general guide, a limit of **3.5 kg/kg** (or g/g) will be imposed on all $CO_2$ yields, based on pure carbon conversion.

An example is given below for a nylon carpet sample tested in a cone calorimeter. The beginning and end of test was defined using the mass loss rate criterion specified in ISO 5660 (1993). However, $CO_2$ yields as high as 3.7 kg/kg are still observed towards the end of test as shown in Figure 5.13.

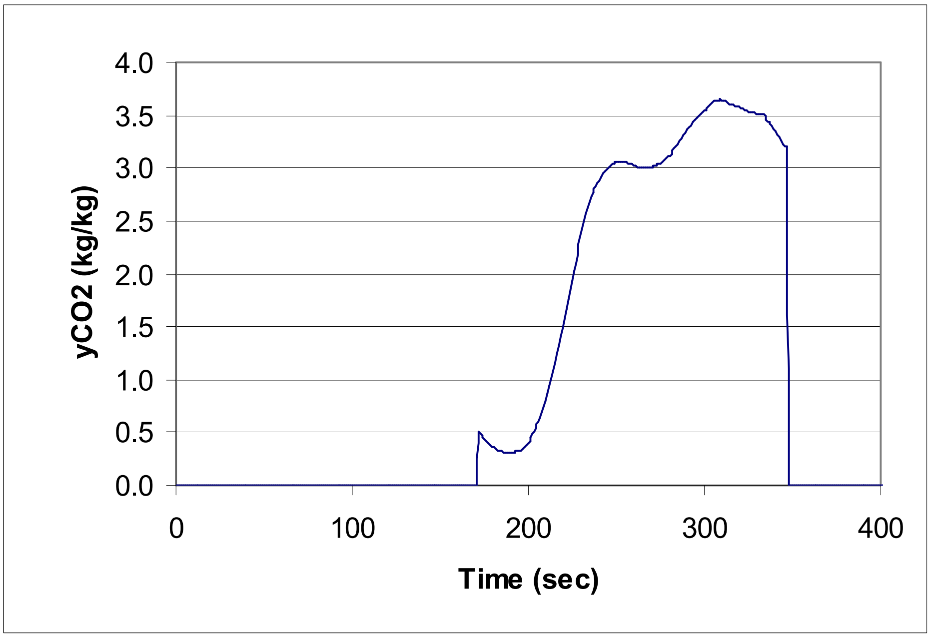



**Figure 5.13 Nylon Fabric Carpet under 20 kW/m$^2$ irradiance, Test 1 (Reproduced from Johnson, 2008)**

Based on stoichiometry, nylon materials should not have a $CO_2$ greater than Table 5.3's $CO_2$ yield of 2.32 kg/kg. The unlimited air $CO_2$ yield from Table 5.4 also imposes a maximum possible $CO_2$ yield limit of 2.06 kg/kg. Nonetheless, these literature derived values are based on pure nylon materials, whereas the example in Figure 5.13 is based on a nylon carpet sample including a backing material of unknown mass. Therefore, where the tested material is not predominantly made up by one material (for example the polyurethane foam in upholstered furniture), the generic $CO_2$ limit of 3.5 kg/kg will be applied.

So far all comparisons have been made for $CO_2$ yields only as it is the dominant fire species produced for all tests under free-burning conditions (therefore more easily determined chemically). The maximum heat of combustion was derived based on literature, which is discussed in more detail in section 9.1. However, little information has been found for maximum CO and soot yields (section 9.1.4 and 9.1.5). Therefore, judgement must be exercised when choosing design values for CO and soot yields, especially when choosing values towards the ends of the fitted distribution.

## 5.6 Carbon Balancing for Tube Furnace Results

As an exercise to verify the results obtained, carbon counting was done for homogeneous samples that have pre-determined empirical chemical formulae for analysis. To calculate yields from a tube furnace, the mass loss rate profile must first be reconstructed using all carbon-containing combustion products such as $CO_2$, CO, HCN, and soot. These productions were calculated separately for each combustion product using Equation 5.3 below, and summed to re-create the mass loss profile. The example calculation, adapted from Gottuk and Lattimer (2002), is given below for calculating the amount of carbon retrieved in the form of $CO_2$:

$$C_{from\ CO_2} = \chi_{CO_2} \times \dot{m}_{duct} \times \frac{M_{CO_2}}{M_{air}} \times \frac{M_C}{M_{CO_2}} \qquad \text{Equation 5.3}$$

Where

| | | | |
|---|---|---|---|
| $C_{from\ CO_2}$ | = | **Carbon retrieval from $CO_2$ production** | **(g/s)** |
| $\chi_{CO_2}$ | = | **Mole fraction of $CO_2$ measured in the tube calorimeter exhaust duct** | **(% or ppm)** |
| $\dot{m}_{duct}$ | = | **Mass flow rate of air through the tube calorimeter exhaust duct** | **(g/s)** |
| $M_{CO_2}$ | = | **Molecular weight of $CO_2$ per mole (44g/mole)** | **(g/mol)** |
| $M_{air}$ | = | **Molecular weight of air per mole (29g/mole)** | **(g/mol)** |
| $M_C$ | = | **Molecular weight of C per mole (12g/mole)** | **(g/mol)** |

Since the balancing is based upon carbon, all carbon-related quantities must be collected, including soot, which was unfortunately not measured in both sets of tube furnace results. Furthermore, an accurate determination of the chemical composition was critical to derive the total amount of carbon lost based on the total amount of sample mass lost.

### 5.6.1 Re-Created Mass Loss Rate Profile - Anderson's LDPE Results

An example of re-created mass loss rate profile inside the tube furnace based on carbon balancing on $CO_2$ and CO is shown in Figure 5.14 below for Anderson's LDPE results (2008). An impressive 93% carbon retrieval was achieved for this material under an equivalence ratio of 0.7 (Anderson, 2008). A relatively constant mass loss rate profile can be seen from 400s to 1000s, verifying the constant mass loss rate assumption. Nonetheless, due to the nature of this research requiring accurate mass records, a reconstructed mass profile without soot measurements could significantly affect any yield values. For this reason, Anderson's (2008) tube furnace results were not included in this research.

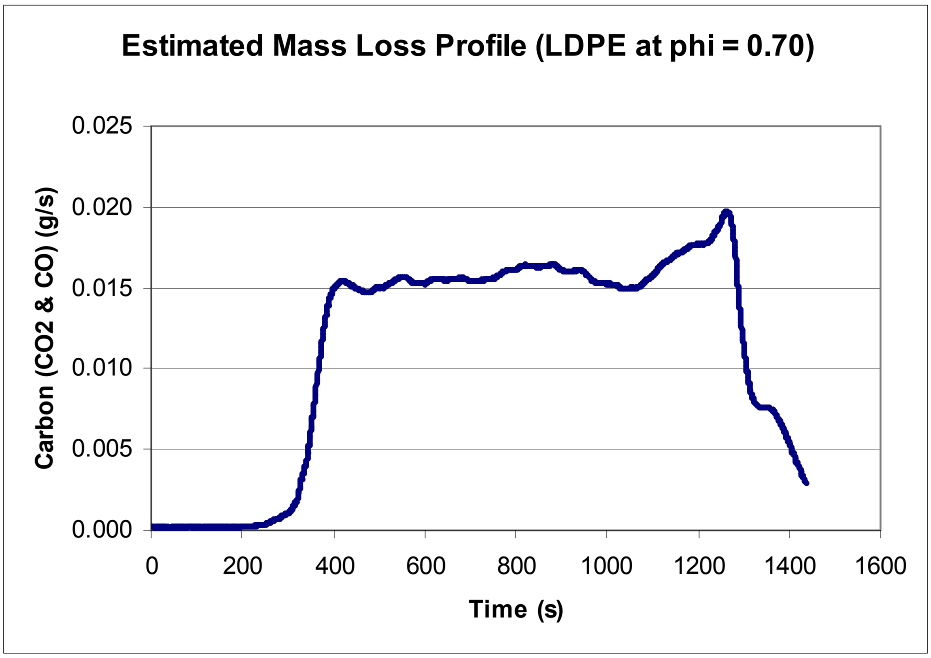



**Figure 5.14 Anderson's LDPE carbon retrieval result – 93% retrieval (Redrawn from Anderson, 2008)**

# 6 Combustion Stage Differentiations

In quantifying the effects of ventilation on fire species yields, three different combustion stages were identified, namely the growth stage, the transition stage, and the smouldering stage. The different groupings were necessary as fuel items involving multiple materials would produce different combustion yields at different stages of the combustion. An example is given below for a typical upholstered chair. In the beginning of the combustion, the main contributing materials would be the covering fabrics and foam materials, while the wooden frame would be involved at a later stage and contribute to the smouldering combustion.

To suit different purposes such as for simulation model inputs, forensic analysis, and comparison to other literature values, the combustion process has been divided into three different combustion stages. A schematic stage divisions diagram is shown in Figure 6.1 below. Figures 6.2 a), b) and c) further explain the stage division and grouping combinations. Criteria for the differentiation is discussed in this chapter, and each stage was fitted individually (all stages, growth stage, transition and smouldering stage, transition stage, and the smouldering stage).

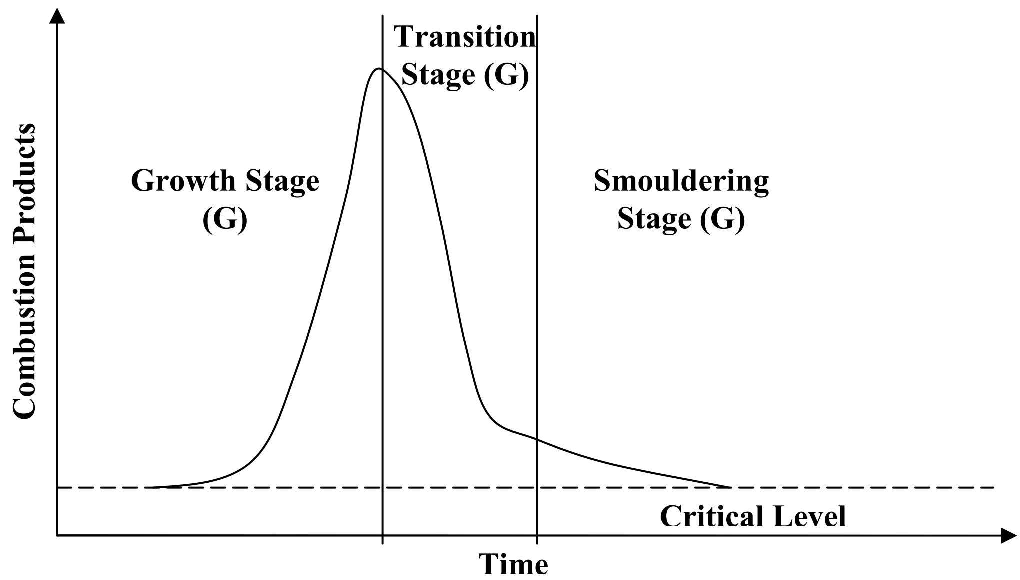



**Figure 6.1 Schematic Division**

| All Stages |
|---|

**Figure 6.2 Stage Divisions**
**a) No stage division**

| Growth Stage (G) | Transition and Smouldering Stages (TS) |
|---|---|

**Figure 6.2 Stage Division**
**b) Two stage division (division criteria discussed in later sections)**

| Growth Stage (G) | Transition Stage (T) | Smouldering Stage (S) |
|---|---|---|

**Figure 6.2 Stage Division**
**c) Three stage division (division criteria discussed in later sections)**

## 6.1 Stage Differentiations

For each test, the combustion was divided into three different stages for analysis and comparisons. These are the growth stage (G), the transition stage (T), and the smouldering stage (S). Furthermore, due to difficulties in precisely distinguishing the smouldering stage (discussed in later sections), experimental results were also analysed as the 'transition plus smouldering stage (TS stage), and the 'all stages' (All stages).

Most literature does not divide the results into different stages, therefore, for the purpose of comparison, no stage differentiation was applied when described as "all stages", where all three stages were grouped together and considered as a single series. This was considered the more appropriate data treatment where limited information is available such as data from the FASTData database. This is because yields values were given directly, and there was insufficient information to derive yield values using equivalent methodologies that were applied on other datasets (refer to Section 5.1 for the mass record smoothing and gradient calculation procedure). In a more extreme case, yields differed by as much as five times as shown in Figure 6.3. The $CO_2$ yield peaked abruptly at around 110s followed by a sustained period of very low

$CO_2$ yield. Approximately one third of the FASTData database exhibited similar characteristics to Figure 6.3 results. These high fluctuations made stage differentiation very difficult and possibly giving misleading results. Consequently, not being able to compare the values on a consistent basis, the analysis was limited to the all stage distribution fittings as it did not seem appropriate to divide results into different combustion stages based on limited information.

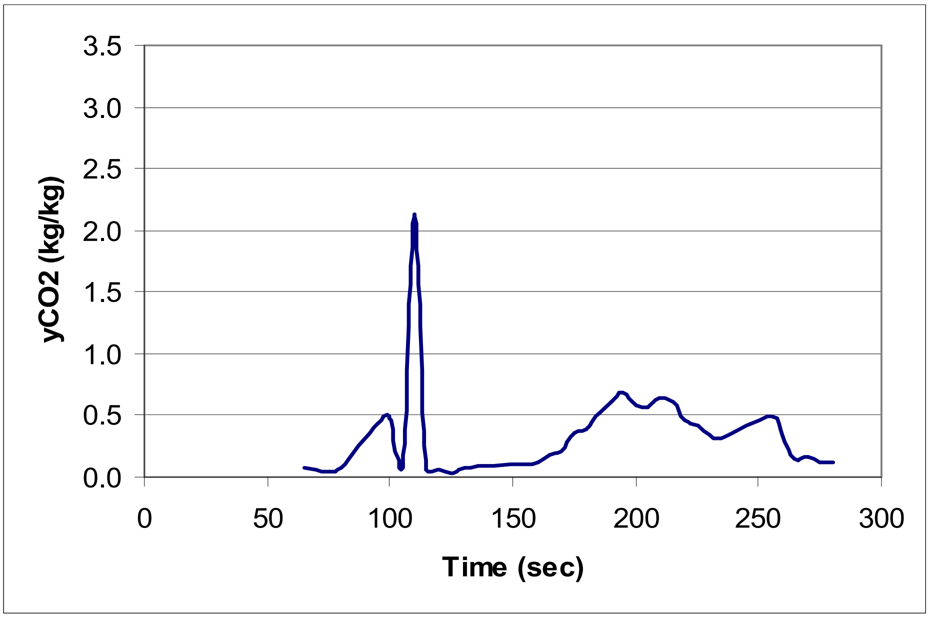



**Figure 6.3** **$CO_2$ Yield Profile for 100% Cotton Fabric and Aramid (Kevlar) Interliner covered Cal 117 Polyurethane Foam with (test "t6226") (Redrawn from NISTFast Data, 1999)**

Changes from one stage to another is often characterised by a rapid change in the heat release rate or the yield profiles, indicating a change in the combustion environment or chemistry. These changes are also reflected through changes in the mean values, standard deviations, and the best-fitted distributions. Typically, the growth stage is followed by the transition stage, which is followed by the smouldering stage until the end of a test. However, exceptions have been observed for fire retarded foam covered by a char-forming fabric. An example is shown in Figure 6.4 with the aviation foam and wool fabric combination in Hill's tests (2003). An initial small peak in heat release rate caused by the ignition source (180 s to 300 s in Figure 6.4) quickly self-extinguished into smouldering combustion. Under a sustained period of smouldering combustion, a much larger heat release rate (800 s onwards in Figure 6.4) occurred in some cases. In cases like these, the first peak is usually ignored as the second peak is the dominant combustion process where the bulk of the material is combusted under a self-sustaining combustion.

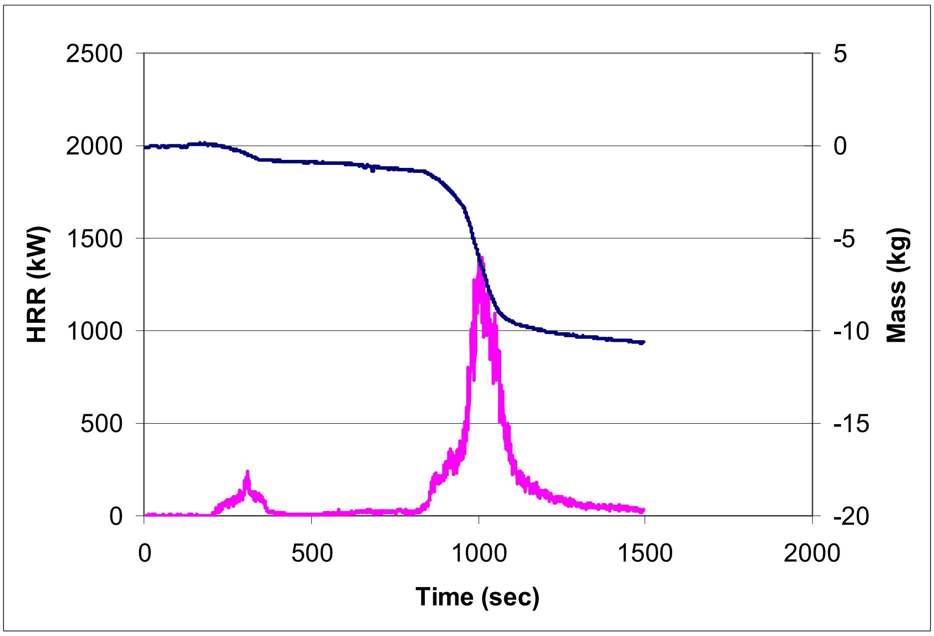



**Figure 6.4 Mass and Heat Release Rate Profiles for Wool Fabric covered Aviation Foam Two Seater (no interliner) (Design S7, trial 1) (Redrawn from Hill, 2003)**

### 6.1.1 Growth Stage

The initial combustion stage is termed the growth stage, and is assumed from the beginning of test until the peak of heat release. This stage assumes high combustion efficiency with high $CO_2$ yield and low CO yield.

The most apparent feature of the growth stage is the constant low CO yield in comparison with later stages. This is because the majority of the carbon is converted to $CO_2$ and the carbonaceous soot that appears in the black smoke during flaming combustion (Mulholland, 2002). Subsequent distribution fittings also confirm that average soot yields are higher during the growth stage (flaming combustion) than during the smouldering stage as shown in Table 6.1.

**Table 6.1 Soot yield Comparisons**

| | Average Soot Yield (kg/kg) | |
|---|---|---|
| | **Growth Stage** | **Smouldering Stage** |
| Non-FR PU Foams Purpose-Built Chairs (Collier and Whiting, 2008) | 0.032 | 0.008 |
| "Real Sofa" (Collier and Whiting, 2008) | 0.022 | 0.012 |
| 100% Modified Polyester Wall Covering on 13mm Plasterboard (Collier, Whiting and Wade, 2006) | 0.074 | 0.005 |
| 100% Polyester Wall Covering on 13mm Plasterboard (Collier, Whiting and Wade, 2006) | 0.041 | 0.006 |
| 4.7mm Glazed Fibre-Cement Board (Collier, Whiting and Wade, 2006) | 0.035 | 0.008 |
| Vinyl Wallpaper on 10mm plasterboard (Collier, Whiting and Wade, 2006) | 0.078 | 0.001 |

Note: Other tests not listed in this table did not have a well-defined smouldering stage for soot yield comparisons

It is also assumed that yields calculated in the growth stage originated from the predominant fuel type involved. For example, the superior domestic foam in Denize's test (2000) and the nylon carpet material in Johnson's test (2008), as shown in Figure 6.5 and Figure 6.6.

### 6.1.2 Beginning of the Transition Stage – Definition Using the Heat Release Rate Profile

While the growth stage and the smouldering stage have been defined by Ohlemiller (2002) as the "fast flaming combustion" and the "slow flameless smoulder", respectively, there is a gradual transition from the growth stage to the smouldering stage. This transition is generically termed the "transition stage" in this research.

Observing the data collected, it can be seen that once the item was successfully ignited, combustion entered into the growth stage as it quickly consumed the fuel package. Then the fire continued to build up its intensity until reaching its maximum heat release rate. Two typical heat release rate profiles from Denize's (2000) furniture calorimeter and Johnson's (2008) cone calorimeter are shown in Figure 6.5 and Figure 6.6, respectively to demonstrate how the end of the growth stage is identified. Both heat release rate and mass change are plotted, indicating most of the mass was consumed during the growth stage, where high mass loss rate also occurred. The rest of the mass was consumed as the fire slowly transformed into the transition stage, and finally into smouldering combustion if char-forming materials were present.

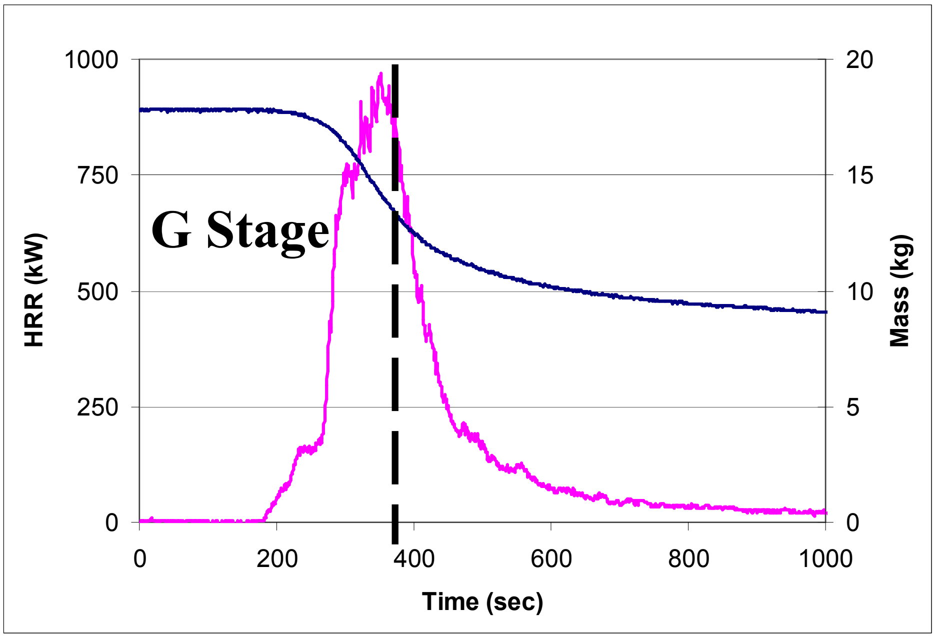



**Figure 6.5 Mass and Heat Release Rate Profiles for Polypropylene Fabric covered Superior Domestic Foam Single Seater (no interliner) (test "Chair I-21-S2-1") (Redrawn from Denize, 2000)**

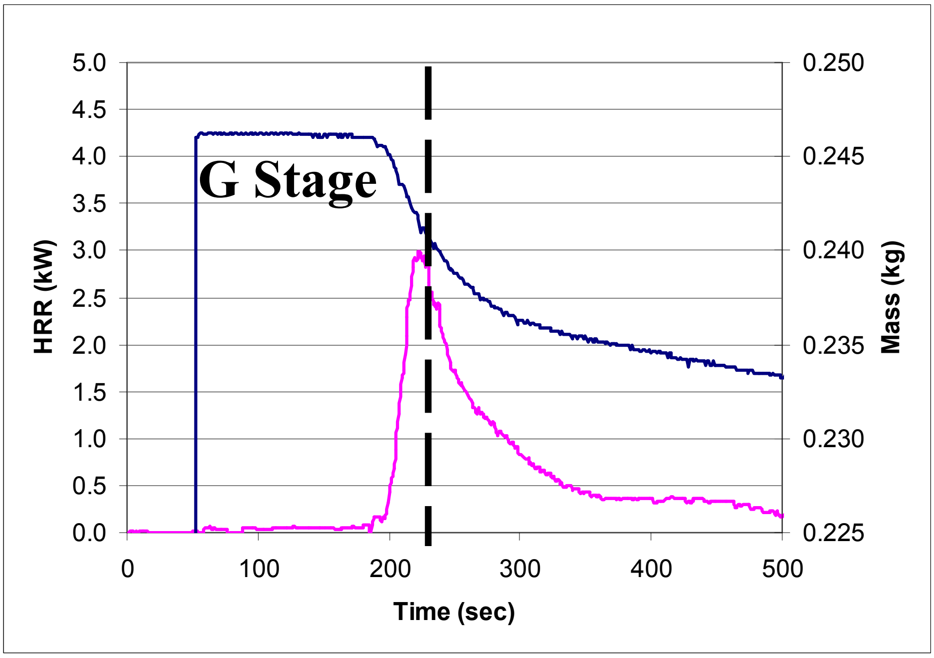



**Figure 6.6** **Mass and Heat Release Rate Profiles for 100% Nylon Fabric Carpet under 20 kW/m² irradiance (test 1) (Redrawn from Johnson, 2008)**

The rapid rise to maximum heat release rate was closely followed by a rapid fall. Many different factors jointly contributed to this sudden change in heat release rate, including changes in the fuel package geometry, amount of radiation feedback, combustion efficiency, effects of charring and many more. All these changes are collectively reflected by the change in heat release rate profile, signifying a distinct change in the combustion process. Consequently, the point immediately following the peak heat release rate is used to differentiate the growth stage from the transition stage.

Transition stage is therefore defined in this research project as the period when the fire gradually transforms from flaming combustion to smouldering combustion, where numerous identified (as well as unidentified) chemical reactions and thermal dynamic interactions took place. CO yields usually rise to an order of magnitude higher than in the growth stage as the transition progresses. In the tests shown above, transition stages for the large scale test and the small scale test began at 370 s and 230 s, respectively as shown in Figure 6.5 and Figure 6.6.

### 6.1.3 Beginning of the Smouldering Stage - Definition Using the Carbon Monoxide Yield Profile (yCO)

Smouldering combustion is a sustained stage of “slow, low-temperature, flameless form of combustion” typically occurring to char-forming materials such as “cellulosic materials derived from plants” (Ohlemiller, 2002). It produces a substantially higher toxic component yield, such as carbon monoxide, although at a much slower rate. It should be noted that not all materials included in this research include a smouldering stage as some did not contain char forming materials. Examples of char-forming materials include porous materials such as cellulose materials and polyurethane foams used in upholstered furniture and bedding. Being porous in nature, these materials provide a high surface area to volume ratio and are permeable to allow oxygen transport by means of diffusion and convection. the chemical composition also allows char formation, which acts as thermal insulators to reduce heat loss, sustaining combustion despite the low heat release rate (Ohlemiller, 2002).

During the transition stage, changes in the combustion mechanism usually cause the CO yield to increase. The beginning of smouldering combustion is therefore identified as when the increase in CO yield during the transition stage comes to, or approaches, a plateau. This is not often easily identified as can be seen from Figure 6.7 and Figure 6.8 below for the corresponding CO yield profiles for the tests shown in Section 6.1.1. Often the mass loss rate thresholds had to be temporarily lowered to observe the trend, in order to ascertain whether or not CO yield has entered into steady yield. In these examples, the beginning of smouldering for Denize’s single seater and Johnson’s nylon carpet tests were 550 s and 300 s, respectively.

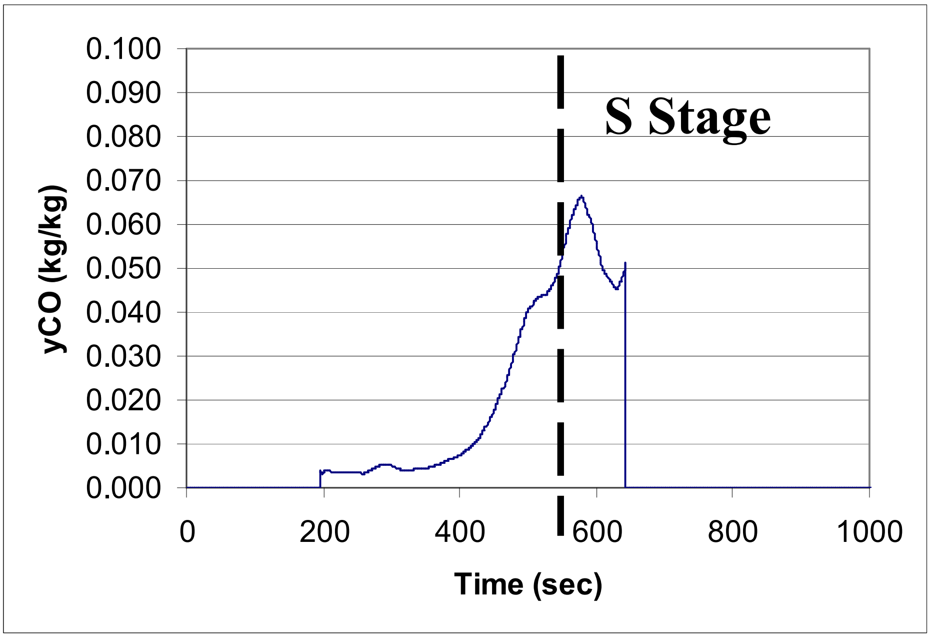



**Figure 6.7 CO Yield Profile (Mass Loss Rate Threshold of 0.005 kg/s) for Polypropylene Fabric covered Superior Domestic Foam Single Seater (no interliner) (test "Chair I-21-S2-1") (Redrawn from Denize, 2000)**

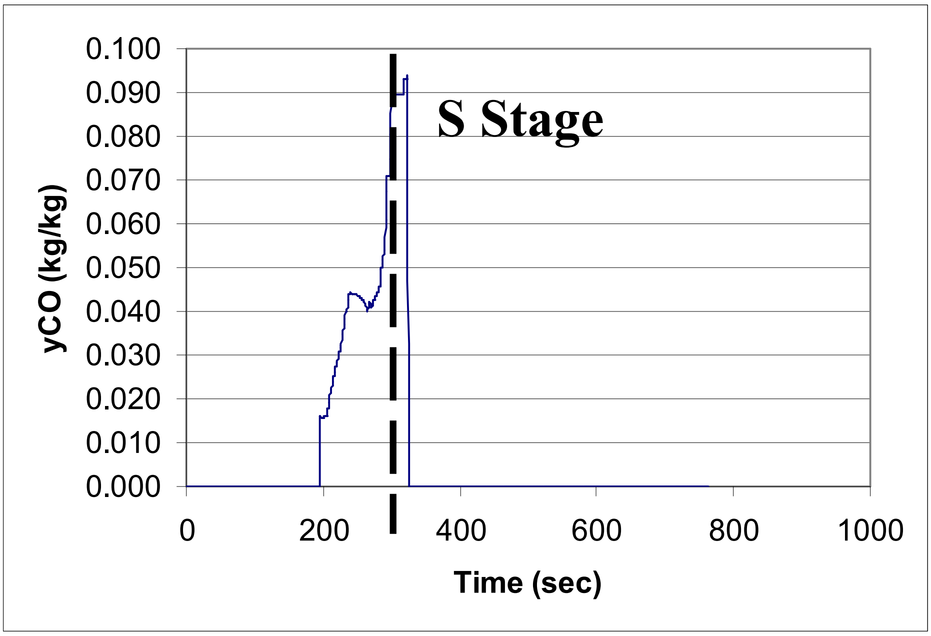



**Figure 6.8 CO Yield Profile for 100% Nylon Carpet under 20 kW/m$^2$ irradiance (test 1) (Redrawn from Johnson, 2008)**

Fire species productions corresponding to mass loss rates below the mass loss rate threshold were not used in this research, as these would create very high yield values that are not physically possible (refer to Section 5.2). Assuming a constant heat of combustion of 20 MJ/kg (typical of polyurethane foams) and applying the 0.005 kg/s mass loss rate threshold (Section 5.3), this is equivalent to a heat release rate threshold of approximately 100kW (20 MJ/kg x 0.005 kg/s = 100 kW). Therefore, when the mass loss rate threshold criterion was applied, a proportion of the smouldering stage became excluded from the final results due to the low heat release rate associated with smouldering combustion. In some cases, the entire smouldering stage has been removed.

Consequently, it often became impossible to clearly define the beginning of a smouldering stage using the CO yield profile, due to fluctuations in the reading, lack of a steady smouldering combustion period, and the result of applying the mass loss rate threshold. Through available video footages for furniture calorimeter tests, it was also observed that complete smouldering combustion never occurred as flickering flames were observed from all video footages until the end of tests (Hill, 2003; Enright, 1999). By the "flameless" definition, the presence of flickering flames indicates it is still in the transition stage. Nonetheless, smouldering combustion was considered the dominant phenomenon towards the end of most experiments, as char-forming materials began to thermally degrade into char. Hence this lends to the necessity to group the transition stage and smouldering stage together as one TS stage, to provide an alternative means of comparison.

### 6.1.4 Grouping Transition and Smouldering Stages

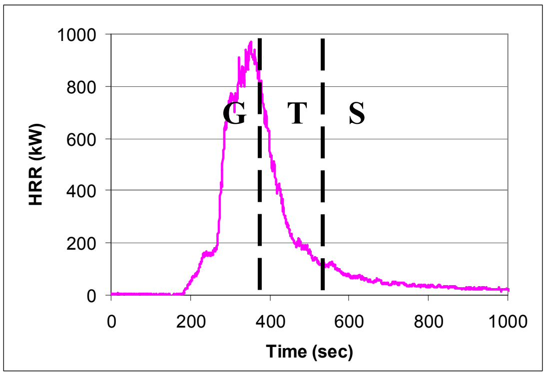
Unfortunately, the CO profiles were also one of the calculated quantities with inherent uncertainties that do not consistently give a clear indication for defining the beginning of a smouldering stage.

The smouldering stage is not always present as well. Where CO yield appears to continue its incline, the smouldering stage is assumed to be completely absent. The absence of a smouldering stage can be attributed to two factors: the mass loss rate during the smouldering stage was smaller than the specified minimum mass loss rate, and the material composition was such that there was no charring material present to allow initiate smouldering combustion.

Therefore, for conservative purposes, the transition stage (T) and the smouldering stage (S) were grouped and analysed as one "transition and smouldering stage (TS)". This effectively divides the test records into two stages of: growth stage (G) and transition and smouldering stages (TS) only (Figure 6.2 b)). To facilitate results comparison, all test results had the additional TS stage created, regardless if smouldering combustion occurred or not.

## 6.2 Combustion Stage Characteristics

The following sections describe the characteristics associated with each combustion stage and explain the existence of each stage division and grouping. Typical yield profiles for $CO_2$ yield, CO yield, and heat of combustion are shown in Figures 6.9 a), b), c) and d) and Figures 6.10 a), b), c) and d) below for a furniture calorimeter test by Denize (2000), and a cone calorimeter test by Johnson (2008), respectively.

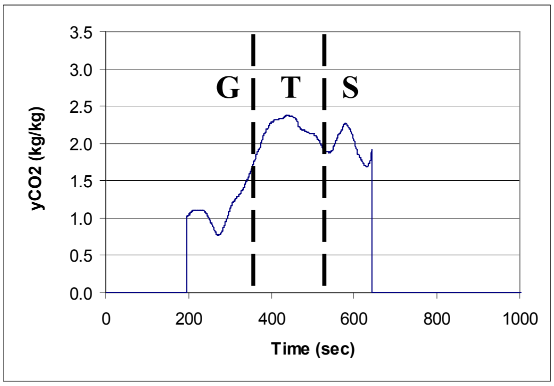



**Furniture Calorimeter Test**

Superior. Domestic. Foam with Polypropylene Fabric

("Chair 9") (Denize, 2000)

**a) Heat Release Rate Profile**




**Furniture Calorimeter Test**

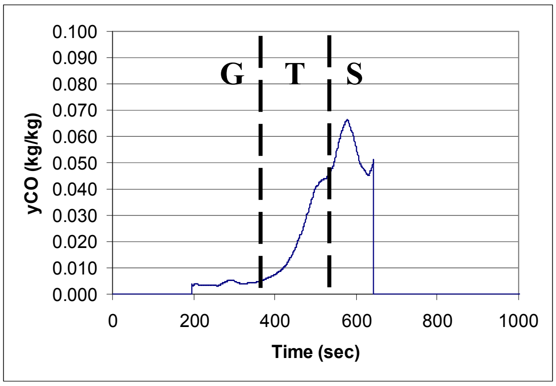
Superior. Domestic. Foam with Polypropylene Fabric

("Chair 9") (Denize, 2000)

**b) $CO_2$ Yield Profile**

Mean = 1.81 kg/kg

St. Dev. = 0.47 kg/kg




**Furniture Calorimeter Test**

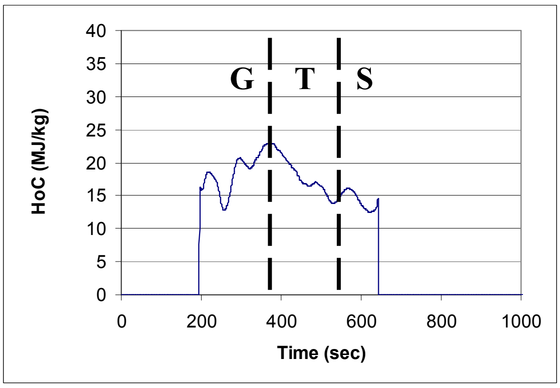
Superior. Domestic. Foam with Polypropylene Fabric

("Chair 9") (Denize, 2000)

**c) CO Yield Profile**

Mean = 0.027 kg/kg

St. Dev. = 0.022 kg/kg




**Furniture Calorimeter Test**

Superior. Domestic. Foam with Polypropylene Fabric

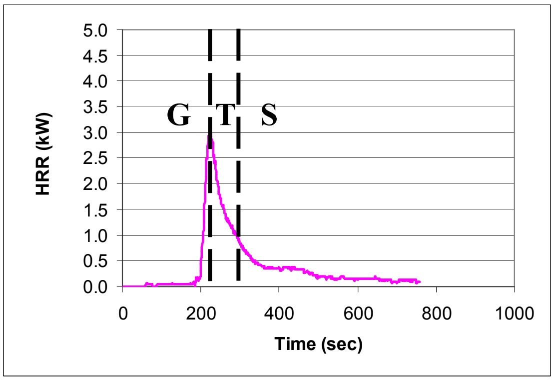
("Chair 9") (Denize, 2000)

**d) Heat of Combustion Profile**

Mean = 17.3 kg/kg

St. Dev. = 3.0 kg/kg

**Figure 6.9 Furniture Calorimeter Test by Denize (2000)**

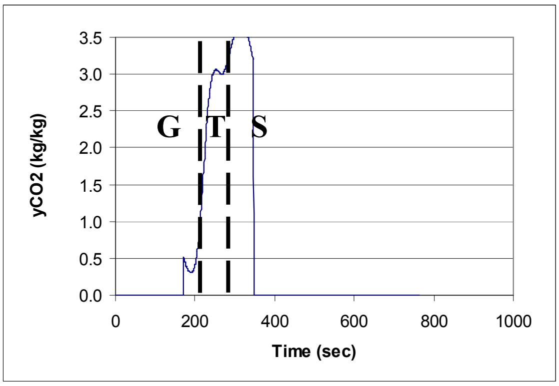



**Cone Calorimeter Test**

100% Nylon Carpet, 20 kW/m$^2$, Test 1

(Johnson, 2008)

**a) Heat Release Rate Profile**




**Cone Calorimeter Test**

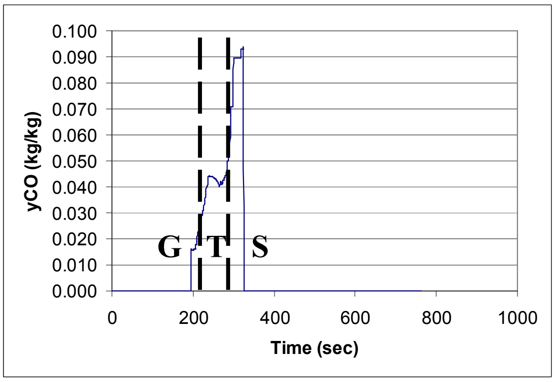
100% Nylon Carpet, 20 kW/m$^2$, Test 1

(Johnson, 2008)

**b) $CO_2$ Yield Profile**

Mean = 2.35 kg/kg

St. Dev. = 1.2 kg/kg




**Cone Calorimeter Test**

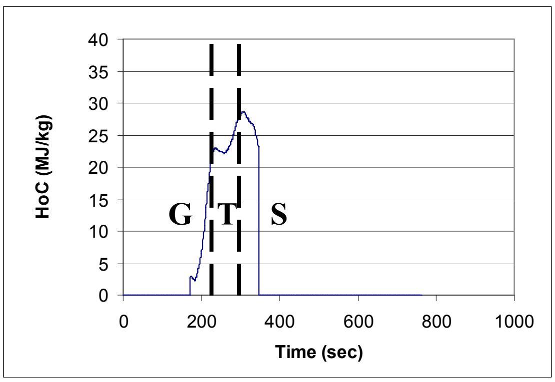
100% Nylon Carpet, 20 kW/m$^2$, Test 1

(Johnson, 2008)

**c) CO Yield Profile**

Mean = 0.049 kg/kg

St. Dev. = 0.024 kg/kg




**Cone Calorimeter Test**

100% Nylon Carpet, 20 kW/m$^2$, Test 1

(Johnson, 2008)

**d) Heat of Combustion Profile**

Mean = 18.7 kg/kg

St. Dev. = 9.5 kg/kg

**Figure 6.10 Cone Calorimeter Test by Johnson (2008)**

## 6.3 Stage Analysis

To demonstrate the changes in yield profiles as the fuel package proceed from the initial growth stage through to the final smouldering stage, an example from Collier and Whiting's (2008) experiment on full scale sofa test (T15) is analysed below. The analysis results for all three different combustion stage groupings are summarised in Table 6.2 below by comparing their respective mean and standard deviation values.

**Table 6.2 Combustion Stage Analysis Summary for Collier and Whiting's (2008) Polyurethane Sofa Furniture Test (T15)**

| Stages | $yCO_2$ (kg/kg) | yCO (kg/kg) | HoC (MJ/kg) | ySoot (kg/kg) |
|---|---|---|---|---|
| **One Stage Analysis – No Stage Division** | | | | |
| **All** | Mean: 1.85<br>St. Dev.: 0.13 | Mean: 0.013<br>St. Dev.: 0.0037 | Mean: 23.9<br>St. Dev.: 1.3 | Mean: 0.017<br>St. Dev.: 0.032 |
| **Two Stages Analysis** | | | | |
| **Growth (G)** | Mean: 1.96<br>St. Dev.: 0.19 | Mean: 0.0089<br>St. Dev.: 0.0013 | Mean: 23.0<br>St. Dev.: 2.1 | Mean: 0.021<br>St. Dev.: 0.0030 |
| **Transition and Smouldering (TS)** | Mean: 1.83<br>St. Dev.: 0.094 | Mean: 0.014<br>St. Dev.: 0.0031 | Mean: 24.1<br>St. Dev.: 0.99 | Mean: 0.016<br>St. Dev.: 0.0020 |
| **Three Stages Analysis** | | | | |
| **Growth (G)** | Mean: 1.96<br>St. Dev.: 0.19 | Mean: 0.0089<br>St. Dev.: 0.0013 | Mean: 23.0<br>St. Dev.: 2.1 | Mean: 0.021<br>St. Dev.: 0.0030 |
| **Transition (T)** | Mean: 1.84<br>St. Dev.: 0.075 | Mean: 0.013<br>St. Dev.: 0.0024 | Mean: 24.1<br>St. Dev.: 0.98 | Mean: 0.016<br>St. Dev.: 0.00088 |
| **Smouldering (S)** | Mean: 1.79<br>St. Dev.: 0.11 | Mean: 0.019<br>St. Dev.: 0.0010 | Mean: 24.5<br>St. Dev.: 1.20 | Mean: 0.014<br>St. Dev.: 0.0018 |

Both the $CO_2$ and heat of combustion profiles remained relatively constant throughout the test while CO yield and soot yield are more sensitive to changes in the combustion conditions. As can be seen from Table 6.2, CO yield has doubled its growth stage value from 0.0089 kg/kg to 0.019 kg/kg, with the highest standard deviation observed during the transition period (0.0024 kg/kg), indicating the greatest change in CO yield occurring during the transition period. Changes in soot yield have been found following a similar profile to $CO_2$ yield, both having an initial peak during the growth stage, followed by a period of steady state yield during the transition, then begin its decline during the final smouldering stage.

# 7 Analysis and Results

Design recommendation for fire species yields are presented in the form of fitted distributions in this research. All data collected have been categorised by material compositions, which are further divided into different stage combinations (three combinations as shown in Figure 6.2 a), b) and c)). The results of the fitted distributions are discussed in this chapter. Following the results are the steps to reconstructing these fitted distributions.

Distribution fitting was performed using @Risk's BestFit application. @Risk is software system for the analysis of business and technical situations impacted by risk (Palisade Corporation, 2009), and the BestFit application in particular allows uncertainties in measurements to be included by providing a probabilistic presentation of the results. Instead of presenting test results using just a few statistical parameters such as means and standard variations, a distribution is fitted using @Risk's BestFit function to describe the data variation with a fitted distribution that can be used as model inputs for probabilistic modelling.

Using these fitted distribution parameters, a Monte Carlo simulation can then randomly select values within the defined distribution to create an output value. With sufficient numbers of such random selections, an output distribution can be created to provide a probabilistic outcome of the fire scenario (and the probabilities of getting those outcomes) for performance-based engineering designs. This identifies not only what could happen in a given situation, but how likely it is that it will happen.

In order to meet purposes ranging from detailed forensic investigations to general design modelling, item categories varied from fine divisions for individual items (by material composition) to generalised grouping from different sources where the exact material composition is uncertain. This is because often the materials to be used in designs are unrestricted; hence a more generalised categorisation is generally necessary to cater for this purpose. Final design recommendations are given in

Chapter 10, while the complete set of fitted distributions are reported in table format, appended at the end of this report in Appendix A.

## 7.1 BestFit Curve Fitting and Reconstruction

Descriptions for the fit results derivations and steps to reconstruct the fitted distributions are described in this section. Although the reconstruction example given is for the @Risk application in Excel only, similar methodologies are also applicable to other distribution generating applications. The final distributions are some of the most fundamental statistical distributions (with simple parameters) such that they will be available in any basic statistical package.

### 7.1.1 BestFit Settings

A brief description of BestFit settings is given in this section, documenting the derivation of the fitted distributions in this research. Twelve distributions were available from BestFit's "Fit Distributions" default settings by fixing the lower limit at "0". This approach was taken as any yields below 0 are physically impossible. (Figure 7.1)

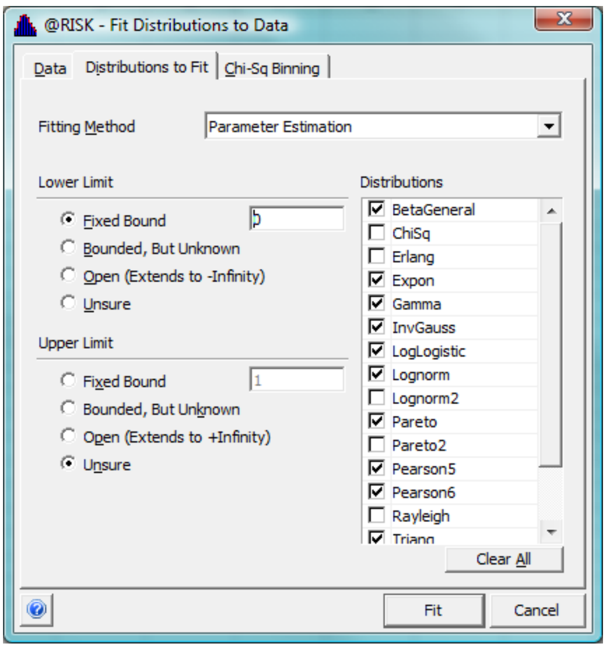



**Figure 7.1 BestFit Limit Settings**
**(Reproduced from Palisade Corporations, 2009)**

By setting this lower limit, some of the distribution functions became unavailable including the Normal distribution. Although truncated distributions are possible in BestFit, it was decided that they will not be considered. Having to specify additional parameters for truncation could add complication to model input, as some models may not have the capability to process a truncated distribution. An investigation was done to compare distributions with and without setting the lower boundary to 0. As will be discussed in a Chapter 9, it was found that in most instances, other available functions such as a Gamma distribution can still closely approximate the symmetrical bell-shaped Normal distribution for symmetrically-shaped distribution profiles. Section 9.2 discusses the effects in fitted distributions by excluding the Normal distribution as a potential distribution function.

While upper bounds can also be fixed, they were left as "Unsure" since each item has a different maximum yield for each of the yield products. Some maximum yields have been calculated stoichiometrically or determined experimentally in the literature; unfortunately this was not available for most items. Therefore, the upper limits were all set to "unsure" for consistency.

### 7.1.2 Distribution Selections

While twelve Distributions were available, only six commonly used distributions were chosen as the final subset (Table 7.1). The subset was chosen based on its simplicity and robustness, and could be easily recreated using most statistical software, requiring only few simple input parameters (Table 7.2).

The final subset was also found to be the only ones capable to fitting a wide range of data (Figure 7.2). Only three distributions could be fitted to one of the larger collection of data, being the gamma, exponential, and uniform distributions (with different chi-squared errors). All of which are from the final subset, as only the more generalised and robust distributions (such as the gamma distribution) were suitable fits for some item combinations.

**Table 7.1 Distribution Selections**

| **12 Distributions from BestFit**<br>(The 6 Distributions forming the Final Subset shown in **bold face**) | |
|---|---|
| Beta General | **Exponential** |
| **Gamma** | Inverse Gaussian |
| Log Logistic | **Lognormal** |
| Pareto | Pearson 5 |
| Pearson 6 | **Triangle** |
| **Uniform** | **Weibull** |

**Table 7.2 Subset Distribution Formula and Parameters**

| **6 Distributions forming Subset** | **Formula and Parameters (in BestFit)** |
|---|---|
| Exponential | **RiskExpon(beta)**<br>decay constant beta |
| Gamma | **RiskGamma(alpha, beta)**<br>shape parameter alpha and scale parameter beta |
| Lognormal | **RiskLognorm(mean, standard deviation)**<br>specified mean and standard deviation |
| Triangle | **RiskTriang(minimum, most likely, maximum)**<br>defined minimum, most likely and maximum values |
| Uniform | **RiskUniform(minimum, maximum)**<br>minimum and maximum |
| Weibull | **RiskWeibull(alpha, beta)**<br>shape parameter alpha and scale parameter beta |

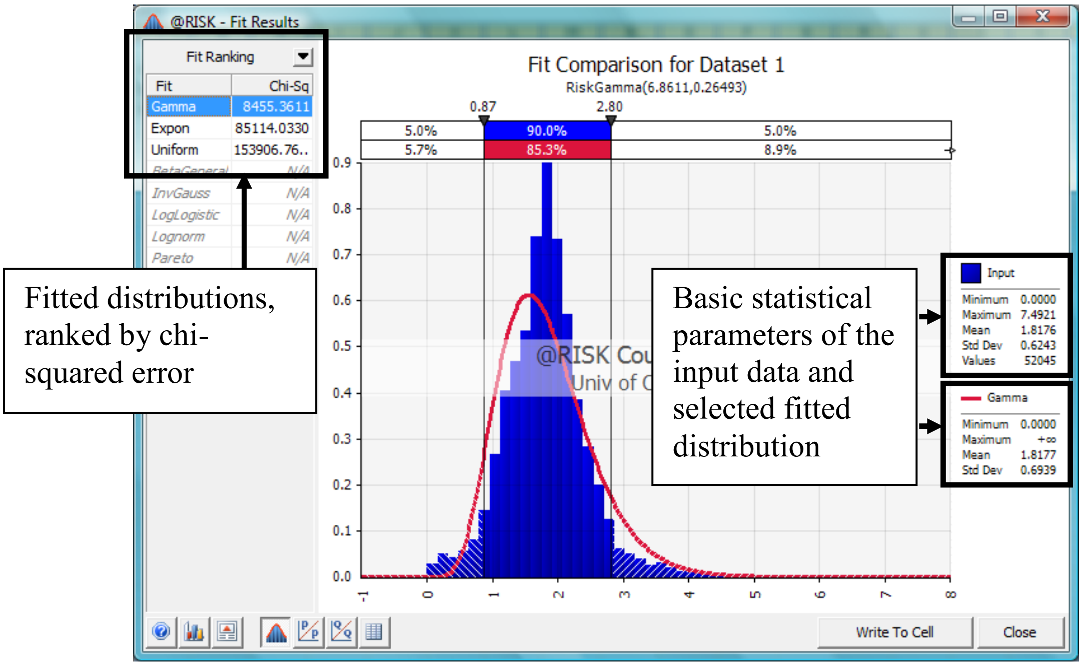



**Figure 7.2** **Fitted $CO_2$ Yield Distribution for "All Tests containing Polyurethane Foams" (Including both FR and Non-FR foams from all cone and furniture calorimeter test, All Stages)**

### 7.1.3 Curve Reconstruction

Distributions can be quickly constructed in BestFit using the parameters reported in Appendix A. This can be done through the "Define Distribution" function, and select the distribution required (Figure 7.3). The example shown is the CO yield for the grouped analysis on "All Carpets" in the smouldering stage. After selecting the Gamma distribution, simply enter the distribution parameters into the "Cell Formula" (Figure 7.4).

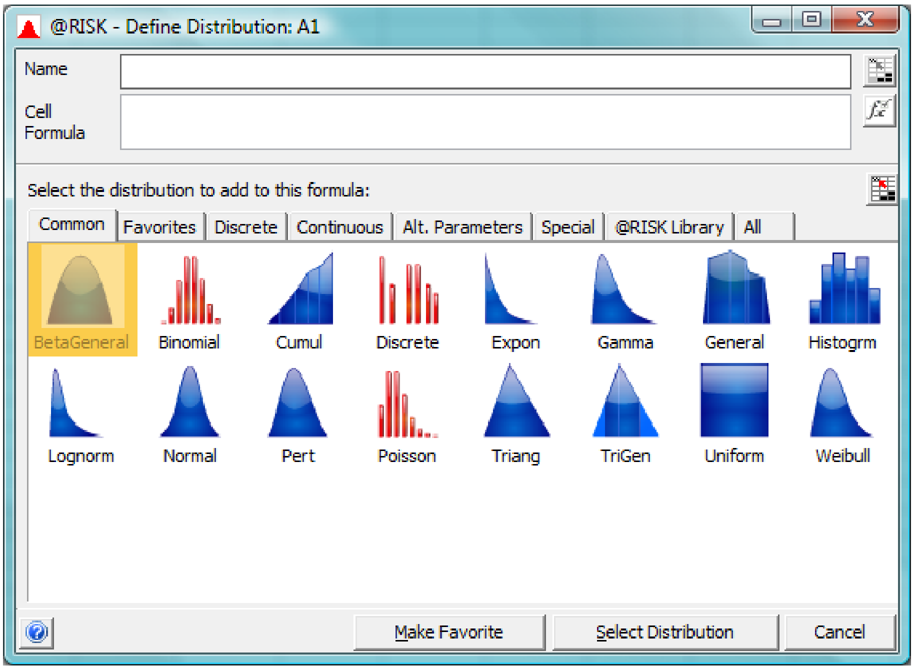



**Figure 7.3** **Select the Distribution for curve re-construction**

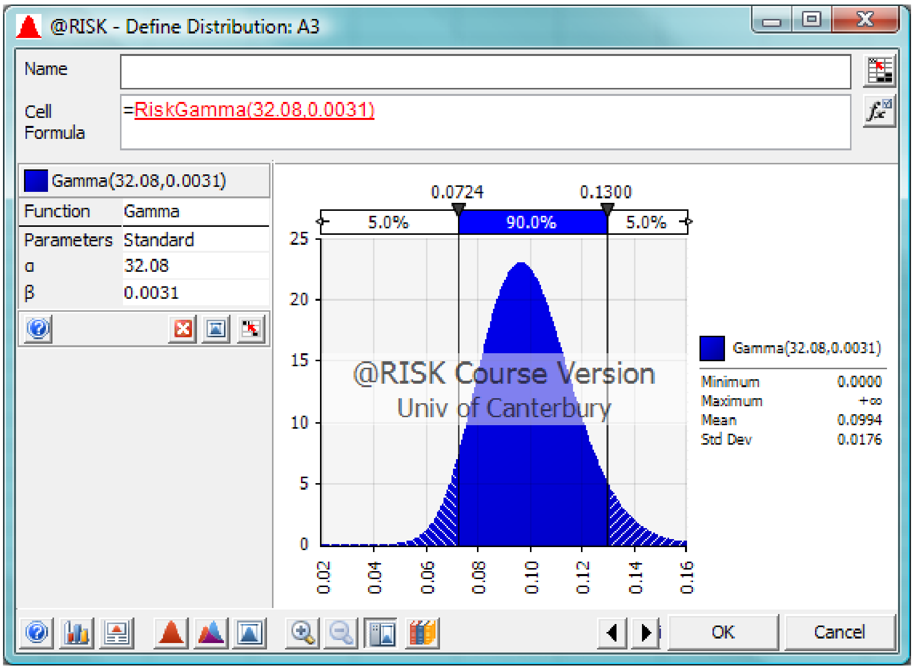



**Figure 7.4** **Input the selected distribution's parameters in the cell formula**

It must be noted that although the fitted distributions reported in Appendix A have been selected based on their robustness and wide range of applicability, they should be used with caution. The absolute minimum yield has been capped at 0 kg/kg or MJ/kg when fitting distributions, but the upper bound must be decided carefully, bearing in mind physical and chemical limitations. It is recommended that where available, maximum yields under stoichiometry or unlimited air supply from literature should be consulted when using values near the higher ends of the curves. Some mean and maximum values from the literature are compared against the fitted distributions and discussed in Chapter 8.

## 7.2 BestFit Results

Fitted results from @Risk's BestFit function are presented in this section, briefly describing results extraction from the generated output and final results presentation in table formats for all four fire species yields.

### 7.2.1 Results Derivation

Following the yield calculations (Chapter 5) and stage differentiations (Chapter 6), all the data were fitted with a distribution. These are further sub-divided into different combustion stage and presented in table format by different material categories in Appendix A.

When all relevant data have been extracted and arranged into a single column in a spreadsheet, a selection of distributions was fitted to the collection. Figure 7.5 below is a typical output for the fit ranked in order by the minimum chi-squared error, which is a common measure for the goodness of fit for curve fitting. The final results are all presented in table format (as can be seen from Table 7.3 and Table 7.4 below), including the maximum and minimum values, the mean, the mode, the standard deviation, and parameters necessary to reconstruct the fitted distribution using the procedures described in Section 7.1.3.

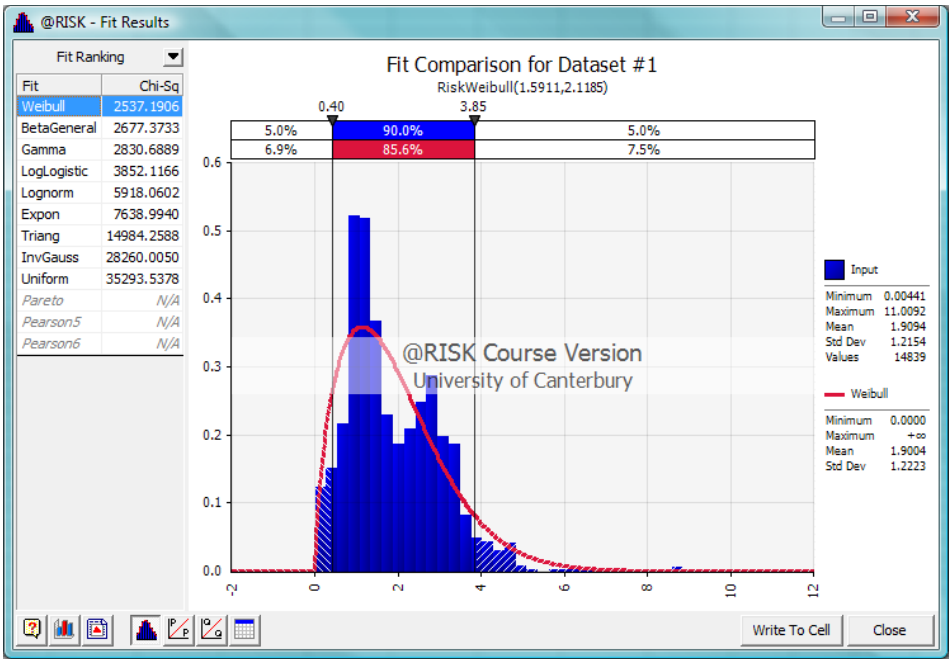



**Figure 7.5** **Fitted $CO_2$ Yield Distribution for "All Carpet Tests" (All Stages) (Redrawn from Johnson, 2008)**

Table 7.3 and Table 7.4 are examples of all the fire species yields from all carpet samples collected in this research (Johnson, 2008), along with some useful percentile values.

The first six columns in Table 7.3 fitted distributions for $CO_2$ yields under different combustion stages. The fit results from Figure 7.5 are tabulated in the second column under the "All" stages grouping. No soot production was measured for the carpet tests by Johnson (2008), therefore the last six columns in Table 7.4 are left as blank.

The generic "carpet" categories would be suitable for design or modelling where the exact carpet material is unknown. All yields available are presented in the three combustion stage grouping as shown in Figure 6.2 a), b) and c) previously. Figure 7.6 below is an example showing fitted results for the heat of combustion under smouldering combustion (S stage). This result is tabulated in the sixth column in Table 7.4.

**Table 7.3 Fitted Distributions and Distribution Parameters for All Carpet Tests - $CO_2$ yield (kg/kg) and CO yields (kg/kg)**

| $CO_2$ Yield (kg/kg) | | | | | | CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Gamma | Weibull | Weibull | Lognorm | **Distrib.** | Weibull | Lognorm | Weibull | Triangle | Gamma |
| **No. Tests** | 47 | 47 | 47 | 47 | 27 | **No. Tests** | 44 | 44 | 44 | 44 | 27 |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 | **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf | **Max.** | +Inf | +Inf | +Inf | 0.1212 | +Inf |
| **Mean** | 1.9004 | 2.0322 | 2.0638 | 2.3156 | 1.6485 | **Mean** | 0.0683 | 0.0327 | 0.0789 | 0.0629 | 0.0991 |
| **Mode** | 1.137 | 1.4831 | 1.4021 | 1.4093 | 1.3226 | **Mode** | 0.0574 | 0.0234 | 0.0765 | 0.0675 | 0.096 |
| **Std Dev** | 1.2223 | 1.0563 | 1.2323 | 1.4761 | 0.6556 | **Std Dev** | 0.0337 | 0.0163 | 0.0295 | 0.0248 | 0.0175 |
| **Alpha (α)** | 1.5911 | 3.701 | 1.7263 | 1.6067 | NA | **Alpha (α)** | 2.1374 | NA | 2.9059 | NA | 32.08 |
| **Beta (β)** | 2.1185 | 0.549 | 2.3153 | 2.5837 | NA | **Beta (β)** | 0.0772 | NA | 0.0885 | NA | 0.00309 |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 0.3276 | 0.6564 | 0.4144 | 0.4068 | 0.8156 | **5%** | 0.0192 | 0.0134 | 0.0318 | 0.0202 | 0.0722 |
| **10%** | 0.515 | 0.8494 | 0.6287 | 0.6367 | 0.9374 | **10%** | 0.0269 | 0.016 | 0.0408 | 0.0286 | 0.0774 |
| **25%** | 0.9682 | 1.2577 | 1.125 | 1.1898 | 1.183 | **25%** | 0.0431 | 0.0213 | 0.0576 | 0.0452 | 0.0868 |
| **50%** | 1.6826 | 1.8523 | 1.8724 | 2.0567 | 1.5318 | **50%** | 0.065 | 0.0292 | 0.078 | 0.064 | 0.0981 |
| **75%** | 2.6013 | 2.6119 | 2.7976 | 3.1662 | 1.9836 | **75%** | 0.0899 | 0.0402 | 0.099 | 0.0809 | 0.1103 |
| **90%** | 3.5784 | 3.4484 | 3.7535 | 4.342 | 2.5032 | **90%** | 0.114 | 0.0536 | 0.1179 | 0.0957 | 0.1221 |
| **95%** | 4.222 | 4.022 | 4.3716 | 5.1147 | 2.8771 | **95%** | 0.1289 | 0.0636 | 0.1291 | 0.1032 | 0.1295 |

**Table 7.4 Fitted Distributions and Distribution Parameters for All Carpet Tests - Heat of Combustion (MJ/kg) and Soot yield (kg/kg)**

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Weibull | Weibull | Weibull | Gamma | **Distrib.** | NA | | | | |
| **No. Tests** | 47 | 47 | 47 | 47 | 27 | **No. Tests** | NA | | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 | **Min.** | NA | | | | |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf | **Max.** | | | | | |
| **Mean** | 15.844 | 17.333 | 15.375 | 18.605 | 10.162 | **Mean** | | | | | |
| **Mode** | 3.0223 | 1.3879 | 3.562 | 4.609 | 4.9145 | **Mode** | | | | | |
| **Std Dev** | 13.700 | 16.212 | 12.930 | 15.477 | 7.3023 | **Std Dev** | | | | | |
| **Alpha (α)** | 1.1598 | 1.0698 | 1.1939 | 1.208 | 1.9366 | **Alpha (α)** | | | | | |
| **Beta (β)** | 16.689 | 17.793 | 16.323 | 19.81 | 5.2473 | **Beta (β)** | | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 1.289 | 1.108 | 1.356 | 1.693 | 1.7328 | **5%** | NA | | | | |
| **10%** | 2.3977 | 2.1713 | 2.479 | 3.073 | 2.6198 | **10%** | | | | | |
| **25%** | 5.7006 | 5.553 | 5.749 | 7.060 | 4.8007 | **25%** | | | | | |
| **50%** | 12.167 | 12.632 | 12.008 | 14.624 | 8.4764 | **50%** | | | | | |
| **75%** | 22.118 | 24.147 | 21.459 | 25.963 | 13.710 | **75%** | | | | | |
| **90%** | 34.256 | 38.800 | 32.824 | 39.522 | 19.914 | **90%** | | | | | |
| **95%** | 42.981 | 49.620 | 40.918 | 49.145 | 24.351 | **95%** | | | | | |

Finer material categorisations are also available. However, they should be used with caution as these are often based on only two or three test results from the same source, making them statistically unreliable.

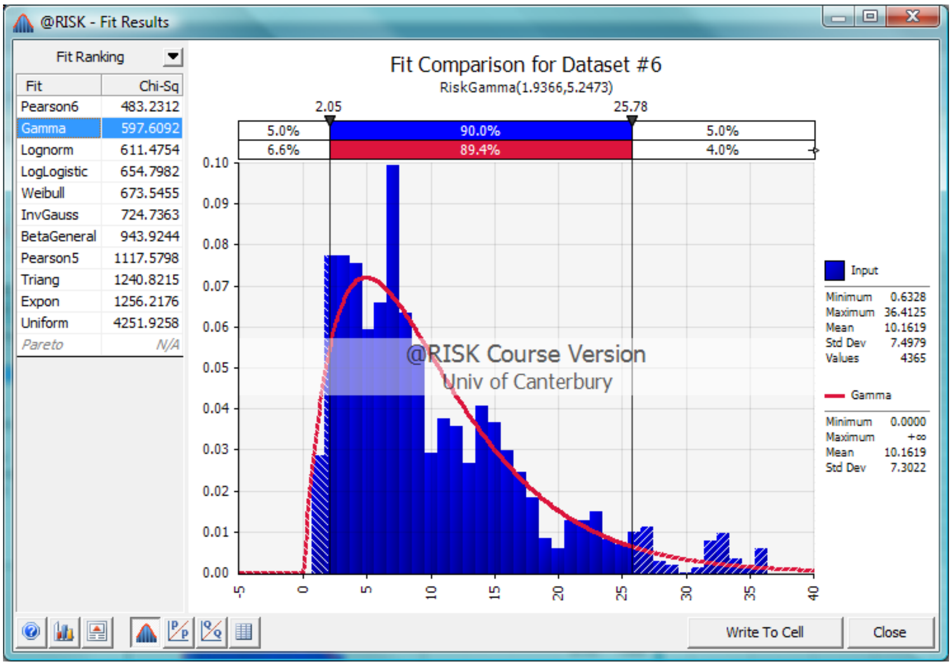



**Figure 7.6 Fitted Heat of Combustion Distribution for "All Carpet Tests" (Smouldering Stage) (Redrawn from Johnson, 2008)**

## 7.3 Distribution Categories

For more practical model simulation and design purposes, the materials are grouped under some broad categories, which are further sub-divided into finer materials categories. Each broad and fine material category also has their respective stage analyses of: all stages (All), growth (G) and transition and smouldering (TS) stages, and growth (G), transition (T), and smouldering (S) stages.

The material categorisations are presented below. Most of the results are different foam and fabric combination tests from different authors. Similarly composed materials are grouped together and analysed under the same category. However, the exact material compositions are unknown (such as the amount of fire retarded additive for fire retarded PU foams). Therefore, occasional discrepancies may occur as a result.

The final recommended distribution categories are highlighted in bold face in Figure 7.7, Figure 7.8, and Figure 7.9. Distribution details for these distributions will be summarised in "Recommendations" in Chapter 10.

### 7.3.1 Upholstered Items

Upholstered items compose the majority of the database presented in this research. These are grouped and categorised as shown in Figure 7.7. All sub-categories have adequate amount of data to statistically capture most of the commonly used upholstered items.

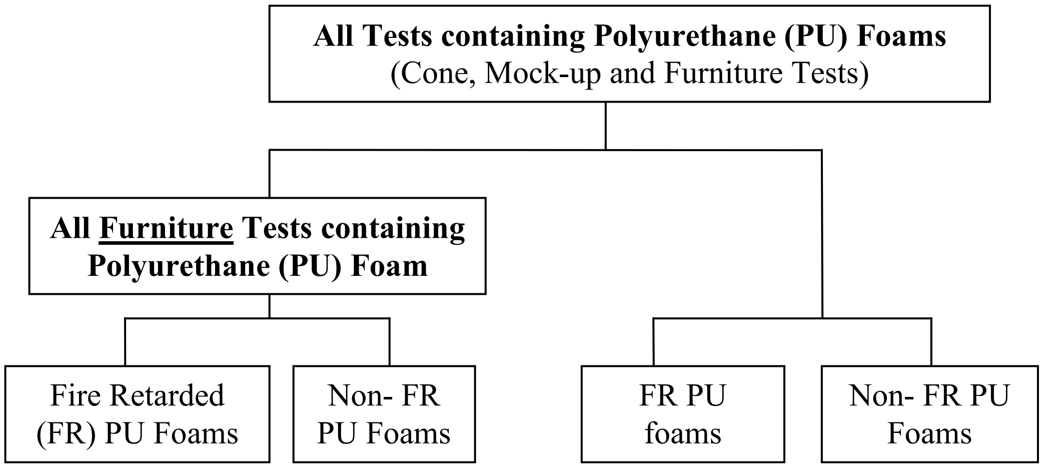



**Figure 7.7 Material Categorisation for Upholsterer Item Tests**

### 7.3.2 Carpets

For carpet results, the generic carpet grouping is made up by four different types of carpet compositions (Figure 7.8). Each sub-category contains 12 tests, tested at four different irradiance levels all conducted by Johnson (2008).

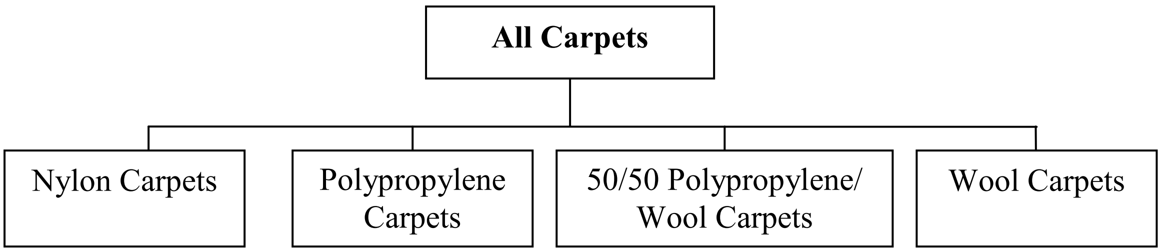



**Figure 7.8 Material Categorisation for Carpets**

### 7.3.3 Wallboards

Wallboard results were sourced from two different researchers (Collier *et al*., 2006; Bong, 2000), comprising a total of nine sub-categories. Each sub-category only has three replicate tests, except the “Weathertex” tests by Bong (2000) which had 11 tests (Figure 7.9).

Typically, wallboards will not be the first items to ignite and are usually only involved in an enclosure environment when flashover occurs. Therefore, free-burn data on these wallboards have a relatively limited application when considering the end use application of this interior furnishing item.

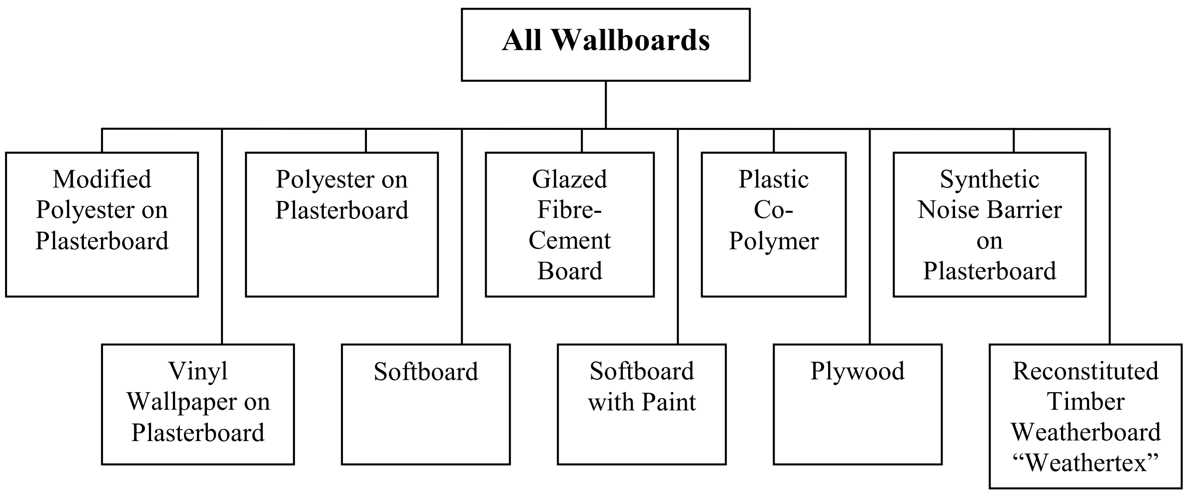



**Figure 7.9 Material Categorisation for Wallboards**

### 7.3.4 Others Items - Trash Containers

Other than items that can be categorised by broad descriptions, there are also some other interior furnishing items (Figure 7.10) that could not be grouped as a material category by itself and require more tests. These tests are insufficient in the number of tests (only two) to generate sufficient data and statistical significance for distribution fitting.

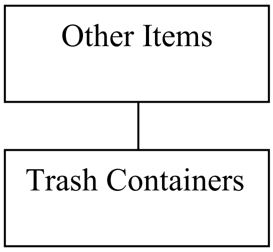



**Figure 7.10 Material Categorisation for Other Items**

# 8 Literature Comparisons

The results of the fitted distributions are discussed in this chapter. Following the results are the steps to reconstructing these fitted distributions using @Risk 5.5's "Define Distribution" function using the given parameters.

The six distributions in the final subset are all frequently encountered distribution functions; therefore, it should be relatively straightforward to reconstruct these fitted in most other statistical programs. Some percentile values are included for convenience, which can also serve as a check for the reconstructed distributions. Full results can be found in Appendix A, where the tests have been grouped under different categories to suit different application purposes.

Fitted results are compared against similar item yields found in literature. As a closer examination, carbon retrieval was also done for four materials to investigate the carbon capture rate of the tests as an indication of possible areas of improvement.

## 8.1 Literature Value Comparisons

When comparing literature values and some characteristic parameters derived from the fitted curves, it has been found that most of the literature mean values are within the fitted distributions' $5^{th}$ and $95^{th}$ percentiles (Table 8.1 to Table 8.4). Where fire-retardants are not specifically stated in literature, it is assumed to be non-fire retarded. However, the broader category of "fire-retarded PLUS non-fire retarded" is also compared to provide more insight on any possible deviations from the literature values. Furthermore, comparisons against literature values have been made for both the "all Stages" and "Growth Stage" distribution fits (refer to Chapter 6 for combustion stage differentiations).

**Table 8.1 $CO_2$ Yield Comparisons (kg/kg)**

| Item Category in Fitted Distributions | Fitted Distrib. Values (kg/kg) | | | Literature Values (kg/kg) | | | Sources |
|---|---|---|---|---|---|---|---|
| | 5th percent | Mean | 95th percent | Mean | Unlim Air | Stoich | |
| ***Polyurethane Foams (Flexible)*** | | | | | | | |
| **All** Tests containing PU Foams, **All** Stages | 0.85 | 1.82 | 3.09 [2] | 1.50 – 1.57 | NA | 2.28 | Tewarson (2002) |
| **All** Tests containing PU Foams, **Growth** Stage | 0.69 | 1.58 | 2.48 [2] | | | | |
| **All** Tests containing **Non-FR** PU Foams, **All** Stages | 0.84 | 1.81 | 3.08 [2] | | | | |
| **All** Tests containing **Non-FR** PU Foams, **Growth** Stage | 0.86 | 1.62 | 2.59 [2] | | | | |
| ***Nylon Carpets*** | | | | | | | |
| **All** Stages | 0.57 | 1.94 | 3.52 [2] | 2.06 | NA | 2.32 | Tewarson (2002) |
| **Growth** Stage | 0.18 | 0.80 * | 2.05 * | | | | |
| ***Polypropylene Carpets*** [1] | | | | | | | |
| **All** Stages | 0.43 | 1.80 | 4.52 [2] | 1.25 – 1.56 | NA | 3.14 | Tewarson (2002) *Materials 'PP-1' and 'PP-2'* |
| **Growth** Stage | 0.19 | 1.80 | 4.59 [2] | | | | |

**Notes**

1 Polypropylene Carpets from Johnson's (2008) experiments and the 'PP-1', 'PP-2', and 'PP' tested by Tewarson (2002) do not seem to be on an equivalent basis for comparison due to:
   a) Mean CO yield range stated by Tewarson does not fall within the fitted distribution's 5th and 95th percentiles (refer to Table 8.2Table 8.2 CO Yield Comparisons (kg/kg)), and
   b) Although Tewarson's mean heat of combustion for 'PP' is within the 5th and 95th percentile, both the fitted distribution mean and the 95th percentile do not compare well with Tewarson's values (refer to Table 8.3)

2 Physically impossible yields - 95th percentile exceeding maximum yields (refer to Section 9.1)

* Literature value does not fall within fitted distribution's 5th and 95th percentiles, and mean value comparisons do not agree (either very different or not within the range stated in literature)

Comparing the polyurethane foams, it seems that the growth stage mean $CO_2$ yield (1.60 kg/kg for all polyurethane foams and 1.66 kg/kg for non-fire retarded foams only) are closer to literature's mean $CO_2$ yield of 1.50 to 1.57 kg/kg (Tewarson, 2002). This is because the literature values were derived from Tewarson's fire propagation apparatus (2002) using only the polyurethane foams, which is the predominant fuel involved in the initial growth stage. The all stages data would include $CO_2$ yields during transition (to smouldering) stage and the final smouldering stage, if the mass loss rate is still above the mass loss rate threshold (Section 5.3).

Although the nylon carpet and polypropylene carpets suggest otherwise, it will be shown later that due to different material compositions (presence of the carpet backing fibre), the carpet samples collected in this research should not be compared against literature polypropylene and nylon data.

**Table 8.2 CO Yield Comparisons (kg/kg)**

| **Item Category in Fitted Distributions** | **Fitted Distrib. Values (kg/kg)** | | | **Literature Values (kg/kg)** | | | **Sources** |
|---|---|---|---|---|---|---|---|
| | 5th percent | Mean | 95th percent | Mean | Unlim Air | Stoich | |
| ***Polyurethane Foams (Flexible)*** | | | | | | | |
| **All** Tests containing PU Foams, **All** Stages | 0.0027 | 0.024 | 0.064 | 0.010 – 0.031 | NA | 1.38 [3] | Tewarson (2002) |
| **All** Tests containing PU Foams, **Growth** Stage | 0.0024 | 0.0094 | 0.023 | | | | |
| **All** Tests containing **Non-FR** PU Foams, **All** Stages | 0.0026 | 0.026 | 0.069 | | | | |
| **All** Tests containing **Non-FR** PU Foams, **Growth** Stage | 0.0022 | 0.0081 | 0.019 | | | | |
| ***Nylon Carpets*** | | | | | | | |
| **All** Stages | 0.028 | 0.078 | 0.136 | 0.038 | NA | 1.48 [3] | Tewarson (2002) |
| **Growth** Stage | 0.012 | 0.028 | 0.050 | | | | |
| ***Polypropylene Carpets*** [1a] | | | | | | | |
| **All** Stages | 0.023 * | 0.054 * | 0.095 * | 0.0029 – 0.0048 | NA | 2.00 [3] | Tewarson (2002) *Materials 'PP-1' and 'PP-2'* |
| **Growth** Stage | 0.018 * | 0.040 * | 0.069 * | | | | |

**Notes**

1 Polypropylene Carpets from Johnson's (2008) experiments and the 'PP-1', 'PP-2', and 'PP' tested by Tewarson (2002) do not seem to be on an equivalent basis for comparison due to:

a) Mean CO yield range stated by Tewarson does not fall within the fitted distribution's 5th and 95th percentiles (refer to Table 8.2Table 8.2 CO Yield Comparisons (kg/kg)), and

b) Although Tewarson's mean heat of combustion for 'PP' is within the 5th and 95th percentile, both the fitted distribution mean and the 95th percentile do not compare well with Tewarson's values (refer to Table 8.3)

3 Stoichiometric CO and soot yields stated in literature, which should not be used as both CO and soot are not primary combustion products (refer to Section 9.1.4)

* Literature value does not fall within fitted distribution's 5th and 95th percentiles, and mean value comparisons do not agree (either very different or not within the range stated in literature)

Mean CO yield comparisons for the polyurethane foams appear to be reasonable. However, the CO yield range of 0.010 kg/kg to 0.031 kg/kg reported by Tewarson (2002) is a wide range. Similarly, since the nylon and polypropylene carpets are later found to be incompatible with the nylon and polypropylene samples tested by Tewarson (2002), a significant discrepancy has been observed for the polypropylene carpets.

It should also be noted that the stoichiometric CO yields reported by Tewarson in Table 8.2 are based on complete chemical conversion into CO, which is not an applicable assumption for secondary combustion products such as CO and soot as this is not physically possible. Consequently, these stoichiometric yields are exceedingly higher than the 95th percentile from the fitted distributions, which are fitted using test results under realistic combustions environments (7th and 4th columns, respectively in Table 8.2)

**Table 8.3 Heat of Combustion Comparisons (MJ/kg)**

<table>
<tr><th rowspan="2">Item Category in Fitted Distributions</th><th colspan="3">Fitted Distrib. Values (MJ/kg)</th><th colspan="3">Literature Values (MJ/kg)</th><th rowspan="2">Sources</th></tr>
<tr><th>5th percent</th><th>Mean</th><th>95th percent</th><th>Mean</th><th>Unlim Air</th><th>Stoich</th></tr>
<tr><td colspan="8">Polyurethane Foams (Flexible)</td></tr>
<tr><td>All Tests containing PU Foams, All Stages</td><td>8.4</td><td>18.3</td><td>31.3</td><td rowspan="4">23.2 – 27.2</td><td rowspan="4">50 [2]</td><td rowspan="4">NA</td><td rowspan="4">Tewarson (2002)</td></tr>
<tr><td>All Tests containing PU Foams, Growth Stage</td><td>7.0</td><td>17.3</td><td>28.2</td></tr>
<tr><td>All Tests containing Non-FR PU Foams, All Stages</td><td>8.5</td><td>18.3</td><td>31.2</td></tr>
<tr><td>All Tests containing Non-FR PU Foams, Growth Stage</td><td>9.1</td><td>17.8</td><td>29.0</td></tr>
<tr><td>All Tests containing Non-FR PU Foams, All Stages</td><td>8.5</td><td>18.3</td><td>31.2</td><td rowspan="2">15.1 – 24.6</td><td rowspan="2">50 [2]</td><td rowspan="2">NA</td><td rowspan="2">Initial Fires (1993)</td></tr>
<tr><td>All Tests containing Non-FR PU Foams, Growth Stage</td><td>9.1</td><td>17.8</td><td>29.0</td></tr>
<tr><td colspan="8">Nylon Carpets</td></tr>
<tr><td>All Stages</td><td>1.6</td><td>16.2</td><td>30.7</td><td rowspan="2">28.0 – 30.8</td><td rowspan="2">50 [2]</td><td rowspan="2">NA</td><td rowspan="2">Tewarson (2002)</td></tr>
<tr><td>Growth Stage</td><td>0.18</td><td>7.4</td><td>25.3</td></tr>
<tr><td colspan="8">Polypropylene Carpets [1 b]</td></tr>
<tr><td>All stages</td><td>1.4</td><td>16.8</td><td>56.8 [2]</td><td rowspan="2">43.2 [4]</td><td rowspan="2">43.2 [4]</td><td rowspan="2">NA</td><td rowspan="2">Tewarson (2002) Pool burning of a homogeneous ‘PP’ solid</td></tr>
<tr><td>Growth Stage</td><td>1.9</td><td>24.3</td><td>66.7 [2]</td></tr>
<tr><td colspan="8">Wool Carpets</td></tr>
<tr><td>All Stages</td><td>1.4</td><td>18.6</td><td>43.3</td><td rowspan="2">20.7 – 26.6</td><td rowspan="2">50 [2]</td><td rowspan="2">NA</td><td rowspan="2">Tewarson (2002)</td></tr>
<tr><td>Growth Stage</td><td>2.7</td><td>15.4</td><td>34.2</td></tr>
<tr><td colspan="8">Beds</td></tr>
<tr><td>All Stages</td><td>12.1</td><td>21.5</td><td>33.2</td><td>20 - 22</td><td>50 [2]</td><td>NA</td><td>Initial Fires (1993)</td></tr>
</table>

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Growth** Stage | 10.3 | 16.2 | 23.8 | | | | |

**Notes**

1 Polypropylene Carpets from Johnson's (2008) experiments and the 'PP-1', 'PP-2', and 'PP' tested by Tewarson (2002) do not seem to be on an equivalent basis for comparison due to:
   a) Mean CO yield range stated by Tewarson does not fall within the fitted distribution's 5th and 95th percentiles (refer to Table 8.2Table 8.2 CO Yield Comparisons (kg/kg)), and
   b) Although Tewarson's mean heat of combustion for 'PP' is within the 5th and 95th percentile, both the fitted distribution mean and the 95th percentile do not compare well with Tewarson's values (refer to Table 8.3)

2 Physically impossible yields - 95th percentile exceeding maximum yields (refer to Section 9.1)

4 The unlimited air yield value is derived from pool burning of the common organic fuels, for polypropylene $(C_3H_6)_n$ in solid form.

Despite the experimental mean heat of combustion values being all lower than Tewarson's (2002) mean values for both the growth stage and the all stages comparisons, they still fall within the mean value range reported in Initial Fires (1993) for polyurethane upholstered furniture. This is anticipated as Tewarson used pure foams in the tests whereas the majority of the fitted distributions are based upon composite materials involving foams, covering fabrics, and the supporting timber frame.

All carpet comparisons are not satisfactory, due to the backing fabric involvement. Although wool carpet's mean values are close to Tewarson's (2002) reported mean values (20.7 MJ/kg to 26.6 MJ/kg) for both all stages and the growth stage.

The all stages comparison for beds are better than the growth stage comparison as Initial Fires (1993) conducted full-scale experiments to obtain these results, similar to the experimental data set-up conducted by Madrzykowski and Kerber (2009).

No stoichiometric heat of combustion is available. Nonetheless, it will be shown in Section 9.1.3 that a reasonable "maximum heat of combustion" can be set at 50 MJ/kg.

Table 8.4 Soot Yield Comparisons (kg/kg)

| Item Category in Fitted Distributions | Fitted Distrib. Values (kg/kg) | | | Literature Values (kg/kg) | | | Sources |
|---|---|---|---|---|---|---|---|
| | 5th percent | Mean | 95th percent | Mean | Unlim Air | Stoich | |
| *All Tests containing Non-Fire Retarded Polyurethane Foams (Flexible)* [5] | | | | | | | |
| **All** Stages | 0.0035 * | 0.019 * | 0.040 * | 0.131 – 0.227 OR <0.01 – 0.035 | NA | 0.593 – 0.622 [3] OR NA | Tewarson (2002) OR Mulholland (2002) |
| **Growth** Stage | 0.017 | 0.028 | 0.044 | | | | |

**Notes**

3 Stoichiometric CO and soot yields stated in literature, which should not be used as both CO and soot are not primary combustion products (refer to Section 9.1.4)
5 No soot yield data is available for FR polyurethane foams.
* Literature value does not fall within fitted distribution's 5th and 95th percentiles, and mean value comparisons do not agree (either very different or not within the range stated in literature)

Most of the test results compare well with literature values. However, when comparing CO yields and soot yields as shown in Table 8.2 and Table 8.4, it was discovered that significant CO yield differences exist for the polypropylene carpets (Table 8.2).

Furthermore, a wide range of soot yield has been reported by Tewarson (2002) in the SFPE Handbook (Table 8.4). While there is considerable overlap between the fitted distribution's range (0.0035 kg/kg – 0.04 kg/kg for all stages comparison) and the Mulholland's values (<0.01 kg/kg – 0.035 kg/kg), there was no overlap between the fitted distribution's range and Tewarson's values (0.131 kg/kg – 0.227 kg/kg) with the mean soot yield values differing by an order of magnitude (0.019 kg/kg from fitted distribution versus 0.227 kg/kg from Tewarson's research).

Without further information of the exact materials used in Tewarson's (2002) and Mulholland's (2002) tests, it cannot be concluded whether the tests are in fact comparable. Further investigation is recommended to determine the reasons for these discrepancies. Some possible causes are discussed in Section 9.3.

### 8.1.1 Carbon Balancing for Some Tests

A preliminary carbon balancing on some items has been done to examine the carbon retrieval through the $CO_2$, CO, and soot measurements. This is a means to verify that yield calculations have been derived appropriately such that what has been lost during combustion has been measured in adequate quantity. The steps taken to calculate the amount of carbon lost and amount of carbon retrieved through $CO_2$, and CO is appended in Appendix C.

As most tests did not measure soot production, it is expected that not all carbons were retrieved. Four materials have been examined, being the nylon carpet, polypropylene carpet, wool carpet, and flexible polyurethane foam (not specifically stated as fire retarded). These were chosen because they involve the least amount of other materials, for example, by not having a covering fabric, so that an estimated chemical formula could be applied to calculate the amount of carbon lost during the combustion.

Despite not being tested with another material, all carpet samples included a backing fibre (Section 9.3.1), of unknown composition resulting in poor comparison other research data in some cases. This nature of the combustion is also unknown. Hence implications of these influences should be considered when evaluating the percentage of carbon retrieval.

It should also be noted that due to limited soot measurements, all examples presented below did not have a soot measurement. All experimental carbon retrievals (third column in Table 8.5) were calculated from $CO_2$ and CO only. Nonetheless, literature reported soot yields (column four in Table 8.5) from the SFPE Handbook (Tewarson, 2002) have been found and noted in the summary table below as comparison. Total carbon retrievals in the last column are calculated by adding columns three and four.

**Table 8.5 Carbon Atom Retrieval Comparison**

| Material | Chemical Formula | Percentage Retrieval from Experimental Measurements | Soot Yield (Literature Values from Tewarson, 2002) | Total Retrieval |
|---|---|---|---|---|
| Flexible Polyurethane Foams ("S0" foams) (Firestone, 1999) | **$CH_{1.74}O_{0.323}N_{0.0698}$** (Tewarson, 2002) | **80% – 82%** | **13.1% – 22.7%** | **93% – 100%** |
| Flexible Polyurethane Foams ("HR0" foams) (Firestone, 1999) | **$CH_{1.74}O_{0.323}N_{0.0698}$** (Tewarson, 2002) | **73% - 83%** | | **86% - 100%** |
| Nylon Carpets (Johnson, 2008) | **$CH_{1.8}O_{0.17}N_{0.17}$** (Tewarson, 2002) | **61% – 79%** | **7.5%** | **69% – 87%** |
| Polypropylene Carpets (Johnson, 2008) | **$(CH_2)_n$** (Tewarson, 2002) | **36% – 72%** | **5.9%** | **42% – 78%** |
| Wool Carpets (Johnson, 2008) | **$CH_{1.53}O_{0.34}N_{0.28}S_{0.022}$** (Ingham, 2009) | **17% – 91%** | **0.8%** | **18% – 92%** |

Flexible polyurethane foams produced a nearly balanced carbon counting, matching closely to 100% (last column of Table 8.5) after summing the experimental CO yield, $CO_2$ yield and literature soot yield from Tewarson (2002). Lower retrieval percentages are observed for the carpet samples, partly attributed to the presence of the backing fibre, and partly due to unsuccessful ignition for wool carpets at lower irradiances.

For nitrogen-containing materials, such as the nylon and the wool carpets, the lack of HCN measurements further attribute to the lower carbon retrieval.

There is also uncertainty about the soot yield stated for polypropylene. Polypropylene is a material with an extremely wide range of application from packaging, textile manufacturing, automobile components, even in medical procedures. As a result, different material forms and chemical compositions would be used for different applications (refer to Section 9.3.1 later). Until further information is available for polypropylene carpet soot yields, the value reported by Tewarson is used to provide an indication for the carbon retrieval estimation.

Since not all carbon containing products were measured in all experiments, a retrieval rate close to unity (100%) is rare. All retrieval rates presented in Table 8.5 are considered reasonable given there are many other undeterminable variables involved. Two of which are the precise determination of the sample's chemical compositions, and lack of soot yield and HCN measurements.

# 9 Distribution Limitations

Representing model inputs in the form of distributions provide a means to present a range of all possible input values. While the mean values may compare well, maximum comparisons for some material categories in Chapter 8 do not (for example, the $CO_2$ yield comparisons for polyurethane foams in Table 8.1). This is because the nature of the distribution means that the end values (for extremely rare cases) may not accurately represent the actual fire behaviour. Furthermore, these end values are usually more sensitive to fluctuations in measurement readings due to the small mass loss rates involved, inaccurate assumptions made, and various possible sources of errors made during the experiment and subsequent data reduction. For this reason, limitations on the use of these results are discussed in this chapter, as maximum possible yields do exist due to physical and chemical limitations.

To prevent negative yields to appear in the fitted distributions, the lower limit was set to 0 for all tests (Section 7.1, Figure 7.1). It was decided that truncated distributions will not be considered as it may limit the application of these research results. The consideration is that truncated distributions require additional input parameters to describe the distribution. This could possibly make it difficult to incorporate into some models, reducing the applicability of this research work. Although some distributions were excluded from the fit in this way, it has been found in Section 9.2 that the six distributions in the final subset can adequately model almost all of the data collection.

## 9.1 Maximum Yields

The fitted distributions sometimes produce yields beyond the realistic limits, most often from small scale tests. Therefore, an upper limit is required to bind the distribution values where a maximum yield or stoichiometric yield is known.

Stoichiometry assumes complete conversion from the reactants to the product of concern. Since $CO_2$ is the primary product for all carbon-containing fuels under sufficient oxygen supply, reactions assuming no production of $CO_2$ are not realistic.

Therefore, it is advised that stoichiometric yields for CO yields and soot yields are not used as the upper limit, as this is often one, or even two, order of magnitude higher than what would normally be expected from a free-burning combustion.

### 9.1.1 Differences in Stoichiometric Yields and Unlimited Air Yields

The differences in stoichiometric yields and unlimited air yields have been previously discussed in Section 5.5 (Table 5.3 and Table 5.4), and found to be different. This is especially true for secondary combustion products such as CO and soot yields (Karlsson and Quintiere, 2000). Although the unlimited air yield is always below the stoichiometric yield, the significant difference for CO yields and soot yields indicate stoichiometric CO yields and soot yields for any products under well-ventilated conditions are not reasonable as the upper limit maximum possible yields.

Every effort was made to minimise fluctuations and extreme values in the data to produce the final results; however, not all factors could be identified and removed as the exact experimental conditions and procedures were unknown. Therefore, judgement must be exercised when selecting values from the distributions. Final yield value selections should be made by considering their unlimited air yields (for primary combustion products). As the scope of this research is limited to free burning items only, it should be noted that under vitiated conditions, certain fire species yields may increase significantly. This includes, but is not limited to, the CO yields. Investigation for fire species yields under different combustion environments is recommended for future studies.

### 9.1.2 Maximum $CO_2$ Yields

Materials relevant to this research with known maximum $CO_2$ yields are summarised in the table below (Table 9.1). For other materials without literature calculated maximum $CO_2$ yields, a generic value of **3.5 kg/kg** was used (refer to Section 5.5).

The unlimited air $yCO_2$ values are all given by Karlsson and Quintiere (2000) as experimentally determined values under unlimited air supply. It is assumed by Karlsson and Quintiere (2000) that these unlimited air yields are constant for a given burning condition. Hence, these data are only applicable to free burning regimes under unlimited air supply.

Unfortunately, it is not known whether the unlimited air yields (column four in Table 9.1) are derived as the absolutely maximum value in a test, or the maximum average value from a number of replicate tests. Nonetheless, comparing the stoichiometric $CO_2$ yields (column three in Table 9.1) and the unlimited air $CO_2$ yields, it can be seen that the unlimited air $CO_2$ yields are just slightly lower than the stoichiometric $CO_2$ yields. This is expected as CO, soot and possibly HCN have also been produced in a realistic combustion scenario.

The only exception is observed from polyurethane foams, where stoichiometric $CO_2$ yield is stated by Karlsson and Quintiere (2000) as 2.21 kg/kg, but the measured unlimited air $CO_2$ yield is only 1.5 kg/kg (Karlsson and Quintiere, 2000). This is most likely due to soot production or other carbon based residues left behind, which was not accounted for in the stoichiometric yield (stoichiometry assumes all reactants are converted into a single product, in this case $CO_2$ only). Polyurethane foams are known to produce a substantial amount of soot during combustion, taking up a significant percentage of carbon which would otherwise form either $CO_2$, or CO, molecules. In addition, being a nitrogen-containing molecule, polyurethane is also expected to produce HCN to some extent, though the amount is expected to be low, it cannot be accurately determined without using the FTIR.

**Table 9.1 Maximum $CO_2$ Yields for Materials Relevant to this Research**

| Material | Empirical Chem. Formula | Stoich. $yCO_2$ (kg/kg) | Unlimited Air $yCO_2$ (kg/kg) | Reference |
|---|---|---|---|---|
| Nylon | $CH_{1.8}O_{0.17}N_{0.17}$ | 2.32 | 2.06 | Karlsson and Quintiere (2000) |
| | | 2.32 | NA | Tewarson (2002) |
| Polypropylene (PP) | $CH_2$ | 3.14 | NA | Tewarson (2002) |
| Polyurethane foam (flexible) (PU) | $CH_{1.74}O_{0.323}N_{0.07}$ | 2.21 | 1.5 | Karlsson and Quintiere (2000) |
| | | 2.17 - 2.28 | NA | Tewarson (2002) (GM21 to GM27) |
| Wood (Douglas fir) | $CH_{1.7}O_{0.74}N_{0.002}$ | 1.72 | NA | Tewarson (2002) |
| Wood (pine) | $CH_{1.7}O_{0.83}$ | 1.40 | 1.33 | Karlsson and Quintiere (2000) |
| | | 1.67 | NA | Tewarson (2002) |

### 9.1.3 Maximum Heat of Combustion

Maximum heat release rate was inferred by examining some average heat of combustion values for pool fires, and was applied over all items collected in this research. Pool fires were examined as they have a homogeneous chemical composition, are readily combustible, and quickly reach a constant value in free burning fires (Karlsson and Quintiere, 2000), hence releasing heat close to its theoretical heat release rates.

Data collections from Babrauskas' (2002) and Tewarson's (2002) included in the SFPE Handbook have been consulted for the maximum heat release rate limit. From which, Babrauskas' pool fire collection is extracted and presented below in Table 9.2. Apart from liquid hydrogen with an average net heat of combustion of 120 MJ/kg, all other materials have an average heat of combustion at or below 50 MJ/kg. Consequently, maximum heat of combustion was fixed at **50 MJ/kg** for all materials examined in this research.

**Table 9.2 Data for Large Pool Fires (Babrauskas, 2002)**

| Material | Density ($kg/m^{-3}$) | $\Delta h_g$ ($kJ/kg^{-1}$) | $\Delta h_c$ ($MJ/kg^{-1}$) | $\dot{m}''$ ($kg/m^{-2}s^{-1}$) |
|---|---|---|---|---|
| Cryogenics | | | | |
| Liquid $H_2$ | 70 | 442 | 120.0 | 0.017 (±0.001) |
| LNG (most $CH_4$) | 415 | 619 | 50.0 | 0.078 (±0.018) |
| LPG (mostly $C_3H_8$) | 585 | 426 | 46.0 | 0.099 (±0.009) |
| Alcohols | | | | |
| Methanol ($CH_3OH$) | 796 | 1195 | 20.0 | See text |
| Ethanol ($C_2H_5OH$) | 794 | 891 | 26.8 | See text |
| Simple organic fuels | | | | |
| Butane ($C_4H_{10}$) | 573 | 362 | 45.7 | 0.078 (±0.003) |
| Benzene ($C_6H_6$) | 874 | 484 | 40.1 | 0.085 (±0.002) |
| Hexane ($C_6H_{14}$) | 650 | 433 | 44.7 | 0.074 (±0.005) |
| Heptane ($C_7H_{16}$) | 675 | 448 | 44.6 | 0.101 (±0.009) |
| Xylenes ($C_8H_{10}$) | 870 | 543 | 40.8 | 0.090 (±0.007) |
| Acetone ($C_3H_6O$) | 791 | 668 | 25.8 | 0.041 (±0.003) |
| Dioxane ($C_4H_8O_2$) | 1035 | 552 | 26.2 | 0.018 |
| Diethyl ether ($C_4H_{10}O$) | 714 | 382 | 34.2 | 0.085 (±0.018) |
| Petroleum products | | | | |
| Benzine | 740 | — | 44.7 | 0.048 (±0.002) |
| Gasoline | 740 | 330 | 43.7 | 0.055 (±0.002) |
| Kerosene | 820 | 670 | 43.2 | 0.039 (±0.003) |
| JP-4 | 760 | — | 43.5 | 0.051 (±0.002) |
| JP-5 | 810 | 700 | 43.0 | 0.054 (±0.002) |
| Transformer oil, hydrocarbon | 760 | — | 46.4 | 0.039 |
| Fuel oil, heavy | 940–1,000 | — | 39.7 | 0.035 (±0.003) |
| Crude oil | 830–880 | — | 42.5–42.7 | 0.022–0.045 |
| Solids | | | | |
| Polymethylmethacrylate | 1184 | 1611 | 24.9 | 0.020 (±0.002) |
| Polyoxymethylene $(CH_2O)_n$ | 1425 | 2430 | 15.7 | |
| Polypropylene $(C_3H_6)_n$ | 905 | 2030 | 43.2 | |
| Polystyrene $(C_8H_8)_n$ | 1050 | 1720 | 39.7 | |

### 9.1.4 Maximum CO Yields

Maximum CO and soot yields could not be specified as stoichiometry does not give reasonable estimates for secondary combustion products such as CO and soot. This is because stoichiometry assumes complete conversion, which does not work for yields apart from the major products such as $CO_2$ and $H_2O$ (Karlsson and Quintiere, 2000). Therefore, although stoichiometric yields for many fire species, including CO and soot, are available from the SPFE handbook, these should not be used. Applying these stoichiometric yields, would give an unrealistically high upper yield limit, which would never happen in a realistic fire scenario.

An example is shown below for an 'All stages' polyurethane foam CO yield distribution (Figure 9.1) and its corresponding soot yield distribution (Figure 9.2), including both the fire retarded and non-fire retarded samples.

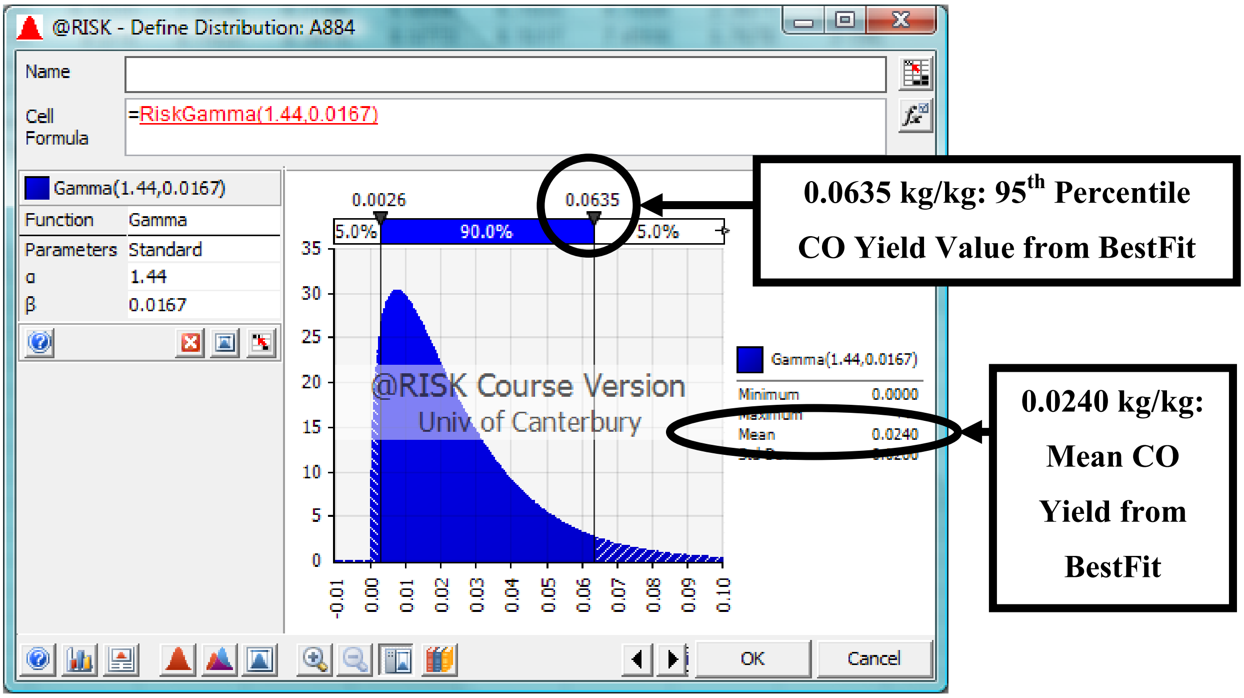



**Figure 9.1 BestFit Reconstructed CO Yield Distribution for "All Tests containing Polyurethane Foams"**
**(Including both FR and Non-FR foams from all cone and furniture calorimeter test, All Stages)**

Although the average CO yield (0.0240 kg/kg) from the polyurethane experiments is close to the Tewarson's average polyurethane CO yield (0.031 kg/kg), the stoichiometric CO yield of 1.38 kg/kg is at least an order of magnitude higher than the 95$^{th}$ percentile of 0.0635 kg/kg. A table of comparison is shown below summarises this CO yield comparison (Table 9.3).

**Table 9.3 CO Yield Comparisons**

| Sources | Mean Yield (kg/kg) | Higher End Comparisons Using Stoichiometric Yield or 95$^{th}$ Percentile Yield (kg/kg) |
|---|---|---|
| BestFit (Figure 9.1) | 0.0240 | 0.0635 (95$^{th}$ percentile of Figure 9.1's fitted distribution) |
| Tewarson (2002) | 0.031 | 1.38 (based on stoichiometry) |

The example illustrates that although the mean values may be comparable, the stoichiometric CO yield should not be used as a reliable upper limit. This is because stoichiometry is defined as a balanced chemical equation giving the exact proportion of the reactants for complete conversion to products, where no reactants are remaining (Karlsson and Quintiere, 2000). As such they tend to be much higher than what would normally be expected since $CO_2$ will always be produced in greater quantities than CO as it is the primary combustion product, although this many not be true in some smouldering combustion cases (Purser, 2002).

### 9.1.5 Maximum Soot Yields

While mean CO values for the flexible polyurethane foams matched closely, soot yield values do not appear to be comparable both in terms of mean yields and maximum yields for the same flexible polyurethane foam collection.

The minimum stoichiometric soot yield for a range of flexible polyurethane foams is 0.593 kg/kg ("GM23" by Tewarson (2002)), which is more than 20 times as high as the mean soot yield (0.0185 kg/kg from Figure 9.2's fitted distribution) and more than an order of magnitude higher than the 95th percentile yield (0.0401 kg/kg from Figure 9.2). Furthermore, Tewarson's "GM23" foam had a mean soot yield of 0.227 kg/kg, which is also more than an order of magnitude higher than the fitted distribution's mean soot yield of 0.0185 kg/kg.

It should be noted that the fitted distributions for furniture items includes contributions from the covering fabrics and the supporting timber frame. Therefore, comparisons should be made against furniture items instead of pure foam materials. Using Robbins and Wade's soot yield results obtained from the furniture calorimeter tests in the CBUF program (excluding the latex foam sample), a more equivalent comparison was made giving a mean soot yield value of 0.027 kg/kg and a 95$^{th}$ percentile of 0.073 kg/kg. Table 9.4 below summarises the soot yield comparisons.

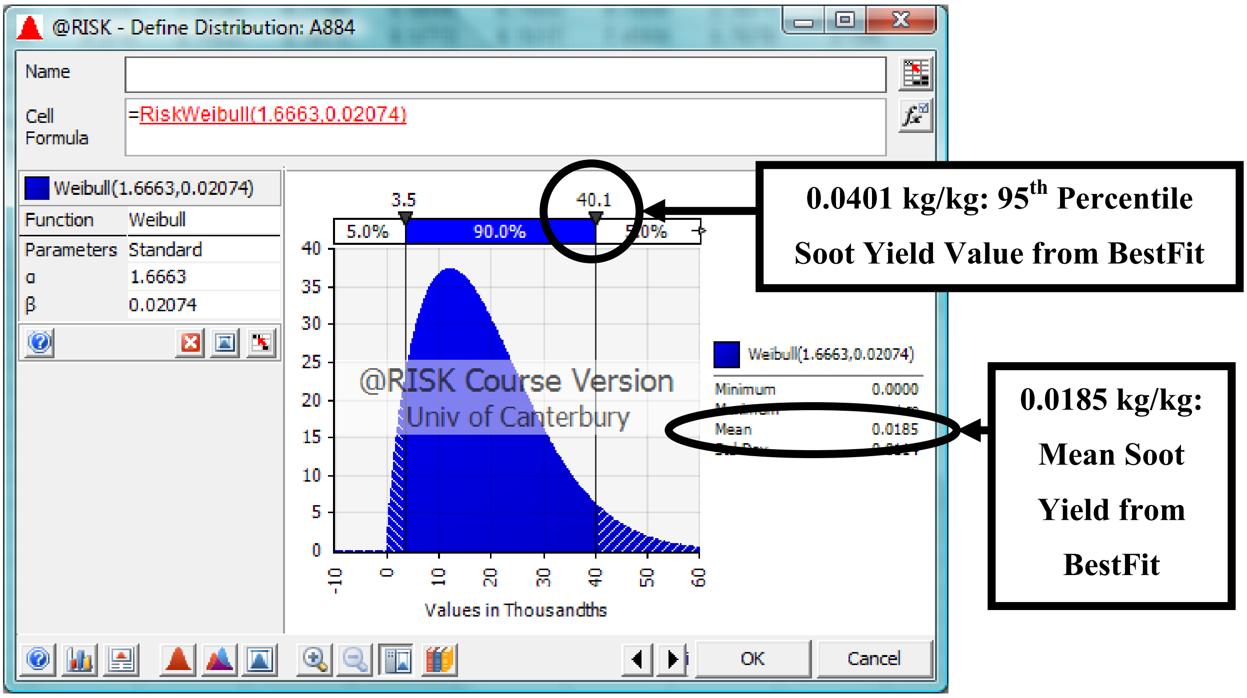



**Figure 9.2** **BestFit Reconstructed Soot Yield Distribution for "All Polyurethane Foams" (Derived from Collier and Whiting (2008)'s Non-FR foams from all mock-up and furniture tests, All Stages)**

**Table 9.4** **Soot Yield Comparisons**

| **Sources** | **Mean Yield (kg/kg)** | **Higher End Comparisons Using Stoichiometric Yield or 95th Percentile Yield (kg/kg)** |
|---|---|---|
| BestFit (Figure 9.2) | 0.0185 | 0.0401 (95th percentile of Figure 9.2's fitted distribution) |
| Tewarson (2002) | 0.227 | 0.593 (based on stoichiometry) |
| Robbins and Wade (2008) | 0.027 | 0.073 |

Unfortunately, data on soot yield is limited both in terms of time series records analysed in this research and literature-stated values determined by other researchers. Consequently, no definitive conclusions could be drawn from these comparisons. Some possible causes for these discrepancies are discussed in Section 9.3, in an attempt to address these problems and suggest how they may be examined in more detail to improve future analysis.

The two examples above illustrate that although the mean values may be comparable, the stoichiometric yields of CO and soot cannot be used as a reliable upper limit as they tend to be much higher than what would normally be expected from a free burning condition.

## 9.2 Non-Truncated Distributions With and Without the Lower Limit

As previously discussed in Chapter 7, some distributions were excluded from the fit when the lower limit was set to a fixed bound of 0 instead of leaving as "Unsure" (Figure 7.1). The reason for fixing the lower limit at 0 is because yields less than 0 kg/kg or heat of combustions less than 0 MJ/kg are not physically possible.

Distribution truncation is available in @RISK to restrict samples drawn from the distribution by specifying the minimum and maximum values. Nonetheless it was decided that this additional process of specifying minimum and maximum values will not be uses for the following two reasons:

1. The truncation function is more useful for random sample generation. Nonetheless, it can also be used in distribution fitting with a minimum value of 0 and a fixed arbitrary maximum of (say) 100 kg/kg or 100 MJ/kg. However, this then becomes the equivalent process of setting the lower limit to 0 and leaving the upper limit to "Unsure", which is the currently adopted methodology in this research.

2. To allow the results of this research to be as easily re-generated as possible, only the most frequently encountered distributions have been considered in the final subset (Table 7.2). Hence, it was decided that truncated distributions will not be used in the research so that even software packages with limit statistical distribution definition capabilities can reproduce the results generated in this research.

By setting the lower limit to 0 instead of leaving it as the default setting of "Unsure", some distributions have been removed as possible fits. These distributions are listed below:

- The Extreme Value distribution,
- The Logistic distribution, and
- The Normal distribution

Of these three distributions, only the Normal distribution would be considered as one of the final distributions making up the subset as the Extreme Value distribution and the Logistic distribution are not as frequently used in other applications. Therefore, the following comparison is made to examine:

1. Whether the Normal distribution gives a superior fit, and

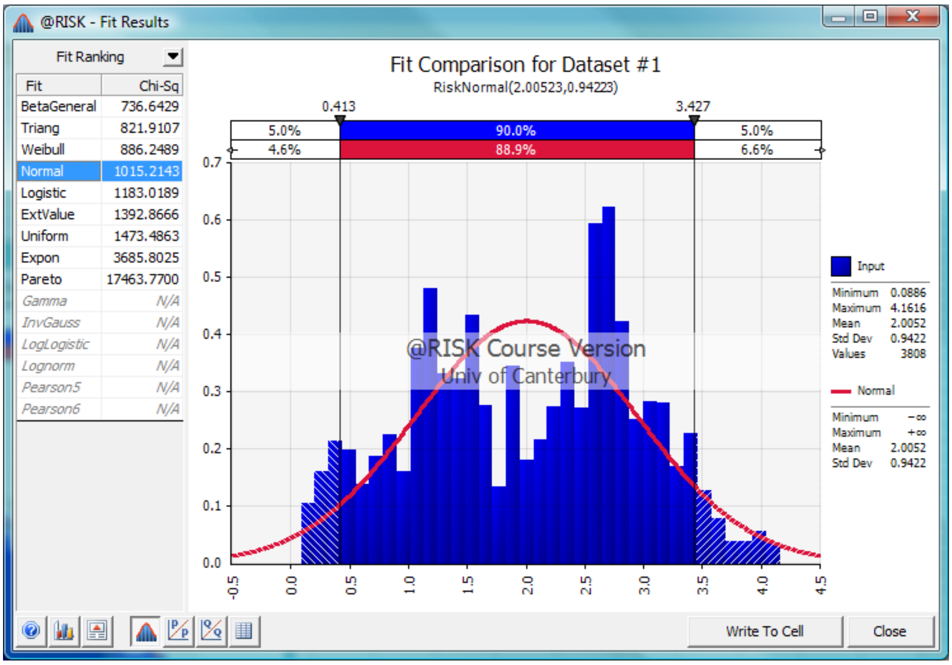
2. Whether or not excluding the Normal distribution would significantly compromise the outcome of the fitted distributions.

### 9.2.1 Fit Results when Setting the Lower Limit to "Unsure"

By setting the lower limit to "Unsure" to include the Normal distribution and allowing negative yields values in the fitted distributions, there is a slight reduction in the chi-squared errors as the restriction (to have all distribution values greater than 0) has been lifted. As a result, the distribution rankings will also be different to when the lower limit is set to 0.

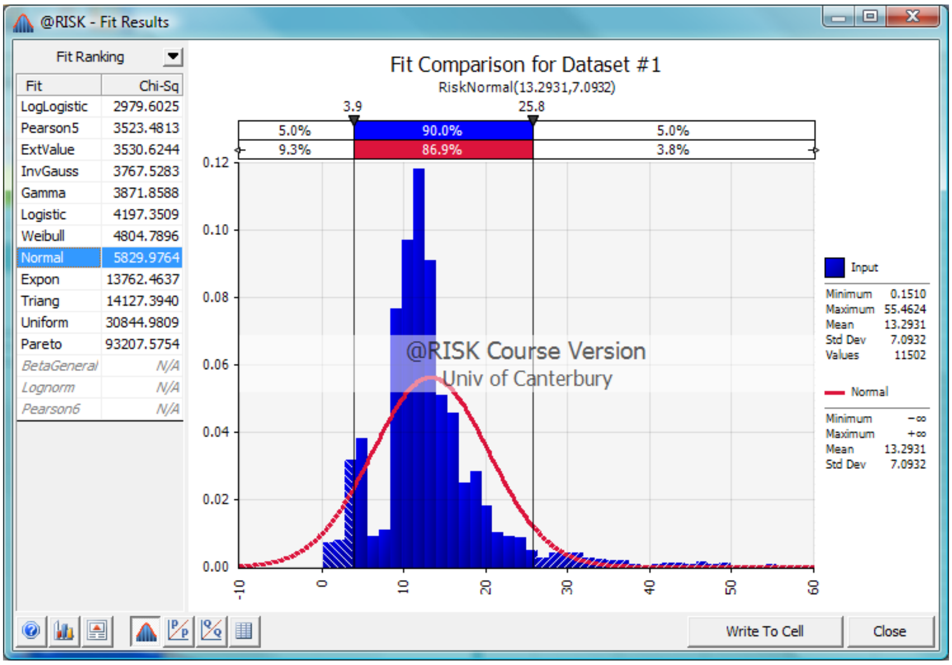
Some distributions have been refitted to examine the differences in fitted distributions. It has been found that in most cases, the top ranking distributions are still the same distributions (Figure 9.3 and Figure 9.4). In one case (Figure 9.5), a Normal distribution provides a slightly better fit with a lower chi-squared error, but a close look reveals that the chi-squared error differences are relatively close. Both mean value and standard deviation of the Normal distribution fit and the final chosen distribution (the Gamma distribution) are very close to each other (Figure 9.5, Figure 9.6 and Table 9.5), when the lower limit is adjusted to "Unsure".

This concludes that the Normal distribution does not necessarily give superior fits, and that by excluding the Normal distribution as one of the possible fit, the final fitted distribution outcomes would not be significantly compromised as the six distributions in the final subset are capable of providing a close enough fit.




| Fit | Chi-Sq |
|---|---|
| BetaGeneral | 736.6429 |
| Triang | 821.9107 |
| Weibull | 886.2489 |
| Normal | 1015.2143 |
| Logistic | 1183.0189 |
| ExtValue | 1392.8666 |
| Uniform | 1473.4863 |
| Expon | 3685.8025 |
| Pareto | 17463.7700 |
| Gamma | N/A |
| InvGauss | N/A |
| LogLogistic | N/A |
| Lognorm | N/A |
| Pearson5 | N/A |
| Pearson6 | N/A |

**Figure 9.3 Johnson's (2008) nylon carpet tests - $CO_2$ yields (All stages)**
**Normal distribution does not give a better fit than the six distributions in the final subset**
(Triangle and Weibull distributions both provide better fits)




| Fit | Chi-Sq |
|---|---|
| LogLogistic | 2979.6025 |
| Pearson5 | 3523.4813 |
| ExtValue | 3530.6244 |
| InvGauss | 3767.5283 |
| Gamma | 3871.8588 |
| Logistic | 4197.3509 |
| Weibull | 4804.7896 |
| Normal | 5829.9764 |
| Expon | 13762.4637 |
| Triang | 14127.3940 |
| Uniform | 30844.9809 |
| Pareto | 93207.5754 |
| BetaGeneral | N/A |
| Lognorm | N/A |
| Pearson6 | N/A |

**Figure 9.4 All Wallboards collection - Heat of Combustion (All stages)**
**Normal distribution does not give a better fit than the six distributions in the final subset**
(Gamma and Weibull distributions both provide better fits)

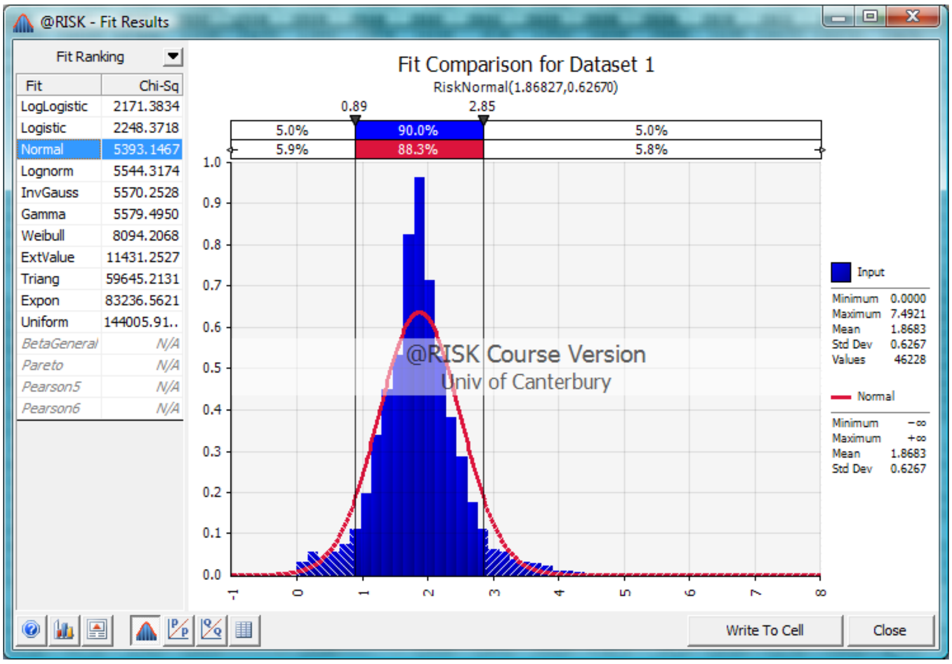



**Figure 9.5** **All tests containing PU Foams - $CO_2$ yields (All stages)**
**Normal distribution gives a slightly better fit**
(showing statistical parameters for the fitted *Normal* distribution)

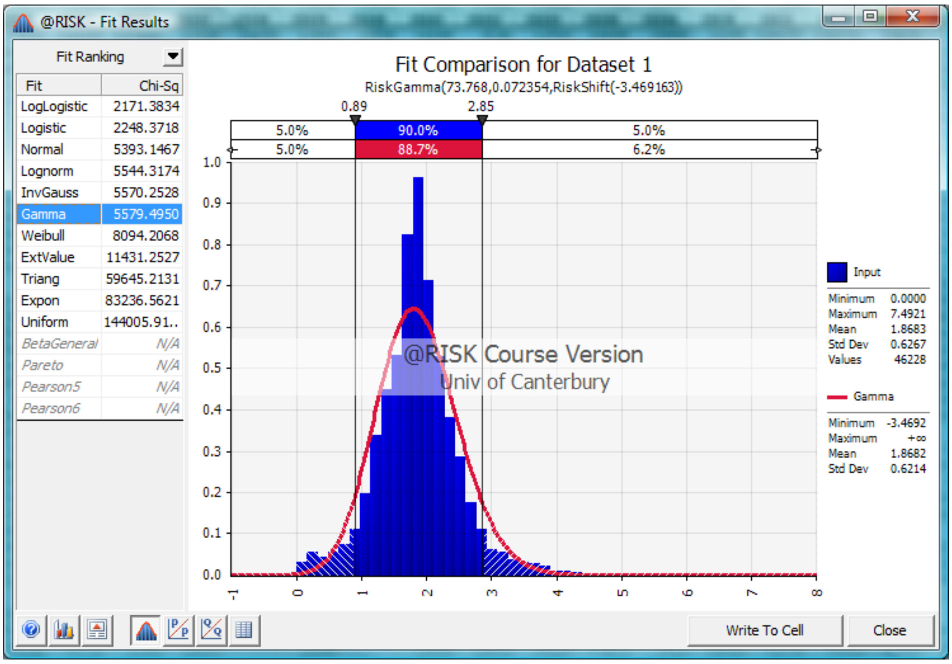



**Figure 9.6** **All tests containing PU Foams - $CO_2$ yields (All stages)**
**Normal distribution gives a slightly better fit**
(showing statistical parameters for the fitted *Gamma* distribution)

**Table 9.5 Difference in Statistical Parameters for "All tests containing PU Foams" category's $CO_2$ yields (All stages), comparing the Normal distribution fit and the Gamma distribution fit**

| Fitted Distributions | Chi-Squared Error | Mean Value | Standard Deviation |
|---|---|---|---|
| Normal (Figure 9.5) | 5393 | 1.868 | 0.627 |
| Gamma (Figure 9.6) | 5579 | 1.868 | 0.621 |

A possible improvement could be to re-fit all the data with truncated distributions (if deemed necessary in the future) as other experimental data becomes available, altering the current distribution profiles.

## 9.3 Causes for Discrepancies

From the literature comparisons in Chapter 8 (Tables 8.3 to 8.6), it can be seen that most of the data collected compared well. However, some discrepancies were found, especially for CO yields and soot yields, where productions are much lower than the more easily measured species such as $CO_2$. Different experimental settings are also expected to contribute to the differences observed.

To discuss these discrepancies, some examples are shown below to illustrate how much the literature values and the calculated distributions differ. It should be borne in mind that since details for many of the items listed in literature are not known, only a limited comparisons could be made, assuming similar chemical compositions.

### 9.3.1 Assumptions on Fuel Configuration, and Composite Material Proportions

Similar configuration, form and material mass proportion were assumed when grouping the items into categories and comparing with literature values. This could be the most likely cause for the poor polypropylene carpet comparison for $CO_2$ yield, CO yield, and heat combustion, shown in the following Sections (Figures 9.7 to 9.9). As the Johnson's (2008) experiments did not measure soot production, no soot yield comparison is available for the polypropylene carpet.

Literature yields for the material closest to the polypropylene carpet description was found from Tewarson's (2002) "PP-1", "PP-2" and solid polypropylene pool burning data. This comparison example illustrates the effects of different fuel configuration and composition material involvements have on the final fire species yields and heat of combustion. Therefore, care must be taken to ensure the materials are compatible when making comparisons against literature values.

### 9.3.1.1 $CO_2$ Yield Comparisons

Tewarson (2002) has stated a mean polypropylene $CO_2$ yield between 1.25 kg/kg to 1.56 kg/kg for the material coded "PP-1" and "PP-2, and a stoichiometric $CO_2$ yield of 3.14 kg/kg for the material "PP" (chemical formula $CH_2$).

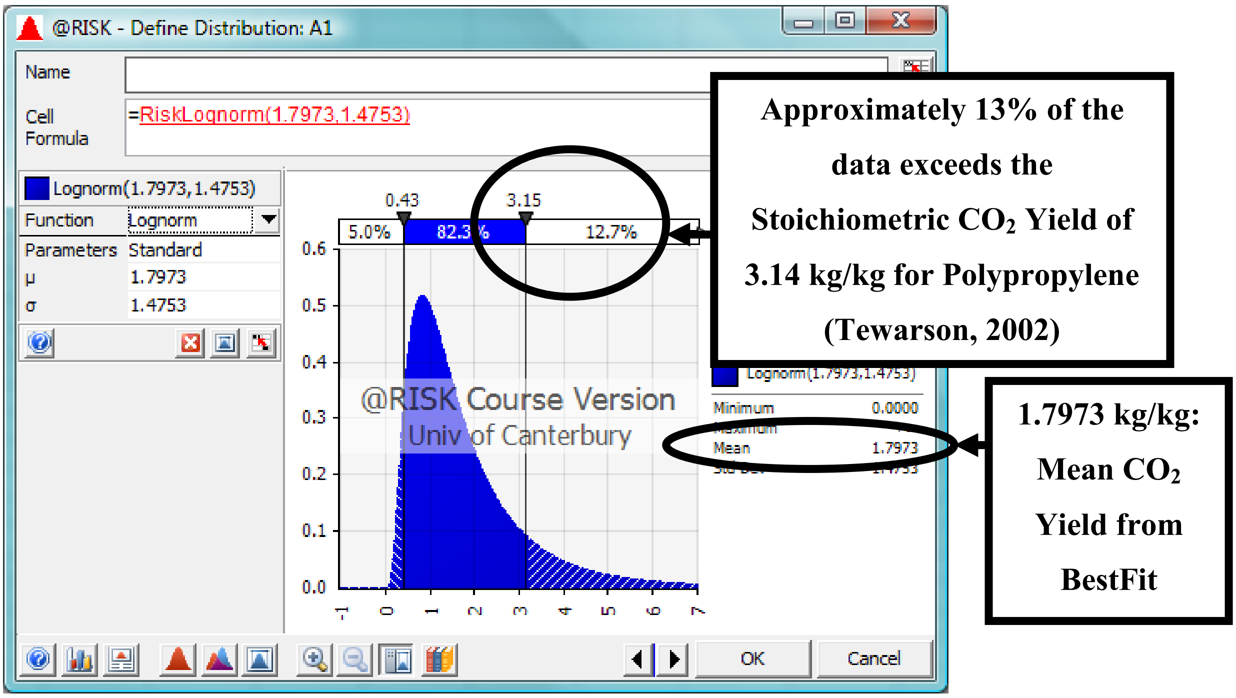



**Figure 9.7 Reconstructed $CO_2$ Yield Distribution for "All Polypropylene Carpet Tests" (All Stages)**

It should be noted that the "PP-1" and "PP-2" data Tewarson (2002) collected were categorised under "Materials with fiberweb, netlike and multiplex structure", while Johnson's polypropylene carpet (2008) would include a backing fibre over which the polypropylene fibre is attached to. The exact chemical composition and the amount of backing fibre involved are both unknown, hence affecting the species productions to an unknown extent.

**Table 9.6 Assumptions on Fuel Configuration, and Composite Material Proportions - $CO_2$ Yield Comparisons**

| | Mean $CO_2$ Yield (kg/kg) | Higher End Comparisons Using Stoichiometric or 95th Percentile Yield (kg/kg) |
|---|---|---|
| PP-1 (Tewarson, 2002) | 1.25 | 3.14 (stoichiometric value) |
| PP-2 (Tewarson, 2002) | 1.56 | 3.14 (stoichiometric value) |
| Polypropylene Carpet (Johnson, 2008) (Figure 9.7) | 1.7973 | Greater than 3.14 (since Figure 9.7's 87th percentile is already 3.15 kg/kg) |

### 9.3.1.2 CO Yield Comparisons

Comparison between Johnson's polypropylene carpet CO yield and Tewarson's polypropylene CO yield also reveals a significant discrepancy, as shown in Figure 9.8. An average CO yield in proximity to 0.0029 kg/kg (for item PP-1) and 0.0048 kg/kg (for item PP-2) is expected based on Tewarson's results, while Johnson's results produced an average CO yield that is an order of magnitude higher, at 0.0541 kg/kg. The characteristics of Johnson's data are unknown to determine whether or not smouldering had occurred during these cone calorimeter tests. The stoichiometric yield is stated by Tewarson (2002) as 2.00 kg/kg for polypropylene ($CH_2$), which is not a realistic value to use (Section 9.1.4).

Mean CO yield and higher end value (either using stoichiometric or 95th percentile) comparisons for literature values and fitted distribution results are summarised in Table 9.7 below.

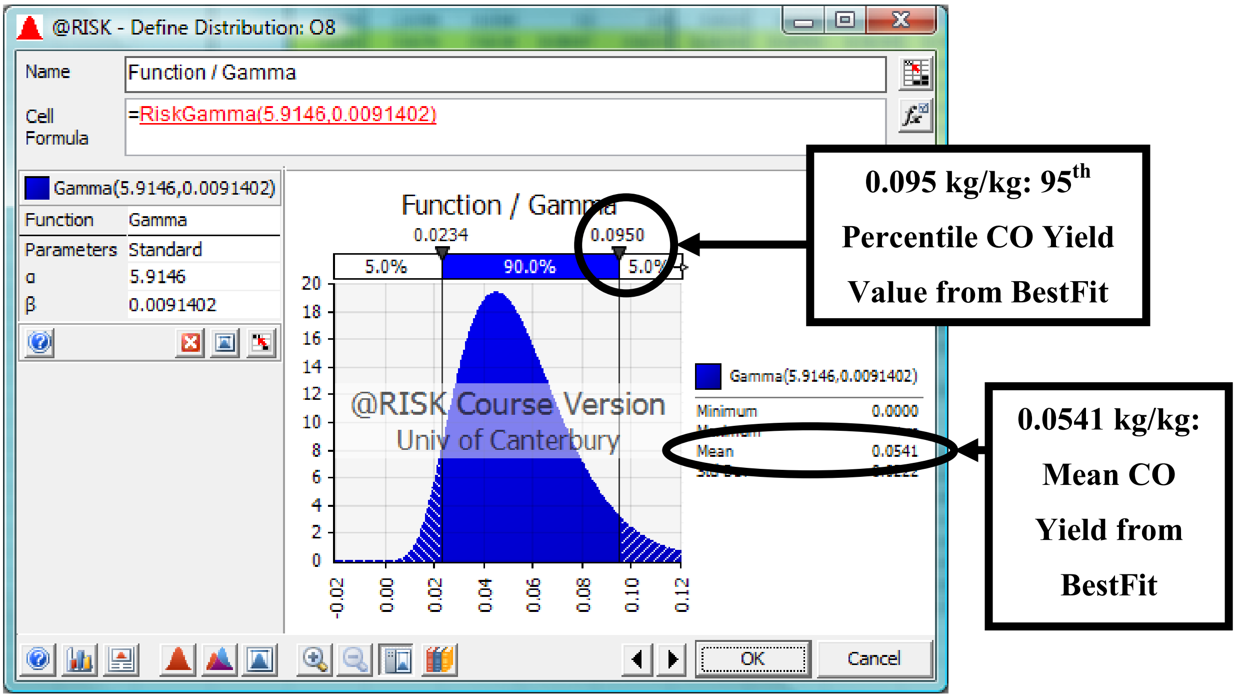



**Figure 9.8** **Reconstructed CO Yield Distribution for "All Polypropylene Carpet Tests" (All Stages)**

**Table 9.7** **Assumptions on Fuel Configuration, and Composite Material Proportions – CO Yield Comparisons**

| | **Mean CO Yield (kg/kg)** | **Higher End Comparisons Using Stoichiometric or 95th Percentile Yield (kg/kg)** |
|---|---|---|
| PP-1 (Tewarson, 2002) | 0.0029 | 2.00 (stoichiometric value) |
| PP-2 (Tewarson, 2002) | 0.0048 | 2.00 (stoichiometric value) |
| Polypropylene Carpet (Johnson, 2008) (Figure 9.8) | 0.0541 | 0.095 (Figure 9.8) |

## 9.3.1.3 Heat of Combustion Comparisons

Discrepancies are also observed in the heats of combustion. Tewarson reported an average heat of combustion of 43.2 MJ/kg for pool burning of solid polypropylene using the flame propagation apparatus, while Johnson's polypropylene carpet gave an average heat of combustion of 16.78 MJ/kg (Figure 9.9).

Mean heat of combustion and higher end value (either using stoichiometric or 95th percentile) comparisons for literature values and fitted distribution results are summarised in Table 9.8 below.

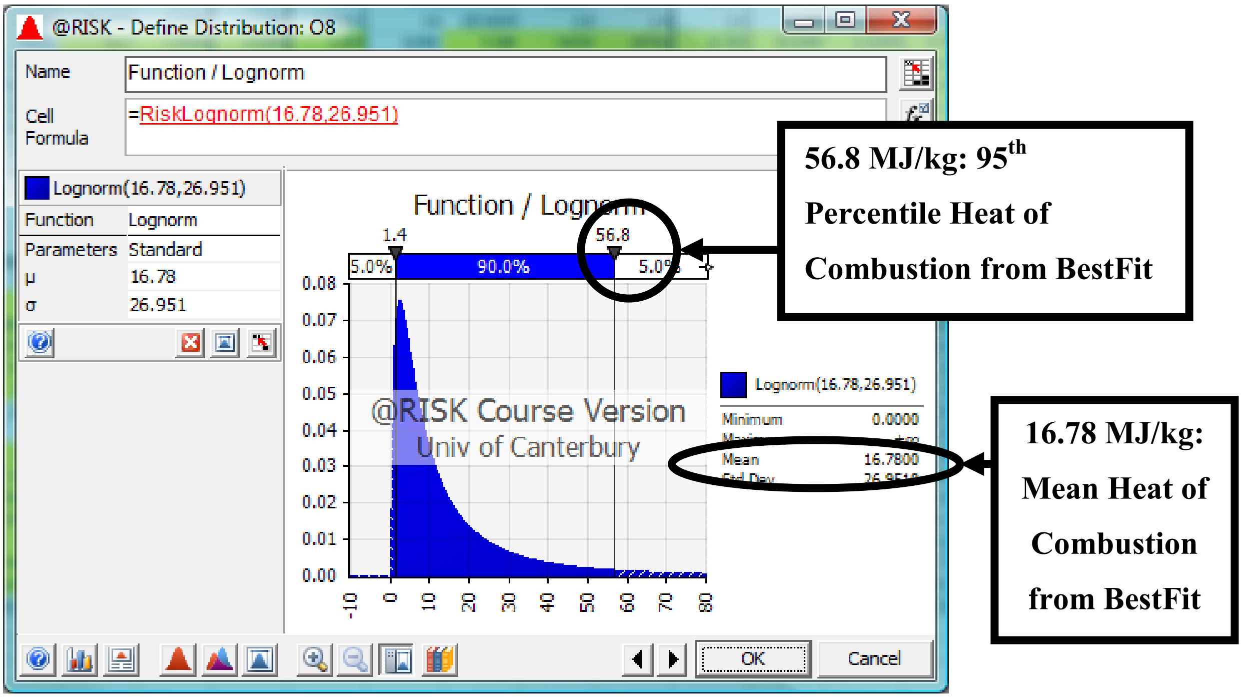



**Figure 9.9 Reconstructed Heat of Combustion Distribution for "All Polypropylene Carpet Tests" (All Stages)**

**Table 9.8 Assumptions on Fuel Configuration, and Composite Material Proportions – CO Yield Comparisons**

| | **Mean Heat of Combustion (MJ/kg)** | **Higher End Comparisons Using Maximum* Heat of Combustion or 95th Percentile Yield (MJ/kg)** |
|---|---|---|
| Pool burning of solid polypropylene (Tewarson, 2002) | 43.2 | 50 (based on pool burning) (refer to Section 9.1.3) |
| Polypropylene Carpet (Johnson, 2008) (Figure 9.9) | 16.78 | 56.8 |

* Refer to Section 9.1.3

The significant difference between the mean heats of combustion may be an indication that these two materials should not be compared at all being significantly different in fuel composition and configuration due to the involvement of the backing fibre.

### 9.3.2 Measurement Techniques

All soot yield data collect in this research were either from the cone calorimeter tests or the furniture calorimeter tests. Tewarson's literature values were collected using the fire propagation apparatus shown in Figure 9.10. Therefore, it is most likely that the discrepancies observed are due to comparing results obtained using different experimental apparatus that involve different measuring techniques.

The presence of a quartz tube also restricts the entrainment pathway to the fire propagation test sample. The fire propagation apparatus tests samples in a semi-open environment inside the quartz tube, while the cone calorimeter tested samples in an open configuration with "free access of air to the combustion zone" (Janssens, 2002). A selection of small and large scale tests has been compared and discussed by Tewarson, summarised in Table 9.9 is the comparison between the fire propagation apparatus and the cone calorimeter.

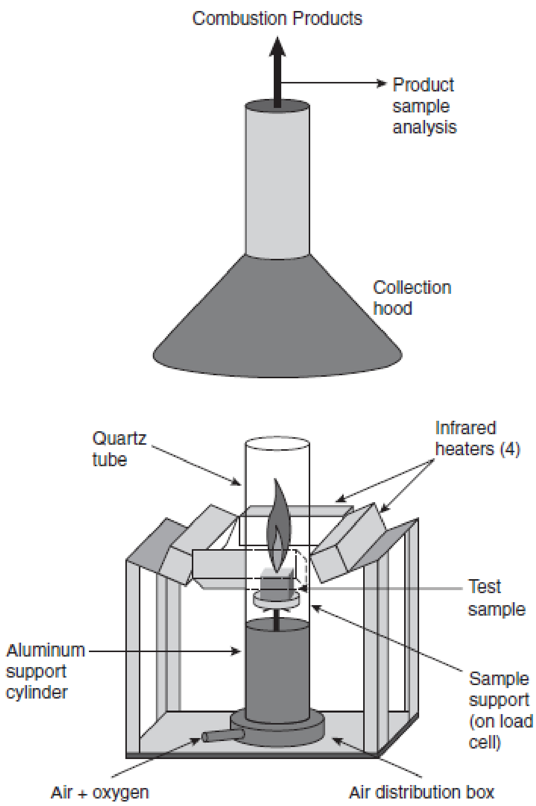



**Figure 9.10 The Fire Propagation Apparatus designed by the Factory Mutual Research (FMR)**
**(Reproduced from Tewarson, 2002)**

**Table 9.9 Design Features and Test Conditions for ASTM E2058 Fire Propagation Apparatus and ASTM E1354 ISO DIS 5660 Cone Calorimeter (adapted from Tewarson, 2002)**

| Design and Test Conditions | ASTM E2058 Fire Propagation Apparatus | ASTM E1354 ISO DIS 5660 Cone Calorimeter |
|---|---|---|
| Inlet Gas Flow | Co-flow/natural | Natural |
| Oxygen Concentration (%) | 0 to 60 | 21 |
| External Heaters | Tungsten-quartz | Electrical coils |
| External Heat Flux ($kW/m^2$) | 0 to 65 | 0 to 100 |
| Exhaust Product Flow ($m^3/s$) | 0.035 to 0.364 | 0.012 to 0.035 |
| Horizontal Sample Dimensions (mm) | 100 x 100 | 100 x 100 |
| Vertical Sample Dimensions (mm) | 100 x 600 | 100 x 100 |
| Ignition Source | Pilot flame | Spark plug |
| Heat Release Rate Capacity (kW) | 50 | 8 |

### 9.3.3 Edge Frame Applications

To define the "end of test" for cone calorimeter tests, ISO and ASTM standards have specified a minimum mass loss rate of "150 g $m^{-2}$ being lost during any 1 min" (Babrauskas, 2002). In cone calorimeter tests, only the exposed area perpendicular to the heat is of concern. All other sides are wrapped in aluminium foil to minimise heat or mass transfer at the specimen edge. Sometime edge frames (Figure 9.11) were used to hold vertically tested specimen from falling out. It is also used to minimise heat or mass transfer at the specimen edge to prevent "unrepresentative edge burning", which is not how its full-scale object would burn. In some other cases, edge frames were required for thermostructural purposes to hold down the edges for materials that exhibit edge warping and curling when subjected to heat (Babrauskas, 2002).

For samples wrapped in aluminium foil only, the exposed area is $0.01m^2$. Using the specified mass loss rate above, this is equivalent to $2.5 \times 10^{-5}$ kg/s. However, for samples using an edge frame (Figure 9.11), the exposed area is reduced to 0.0088 $m^2$. Effectively, this lowers the mass loss rate limit to $2.2 \times 10^{-5}$ kg/s, producing higher yields than those without edge frames. The lowered mass loss rate threshold is therefore one of the causes for higher observed yields in cone calorimeter tests.

Initially, only the exposed area of $0.0088m^2$ is exposed to the heat if an edge frame was used. Once the item is ignited and the flame propagates along item surfaces in all directions, the exposed surface area became irrelevant in terms of combustion. However, the presence of the edge frame does affect the supply and flow of air and fire effluents to some unknown extent. This effectively reduces the exposed area to somewhere between 0.01 $m^2$ and 0.0088 $m^2$. Conservatively, the lower limit of 0.0088 $m^2$ was used, hence creating slightly higher yields.

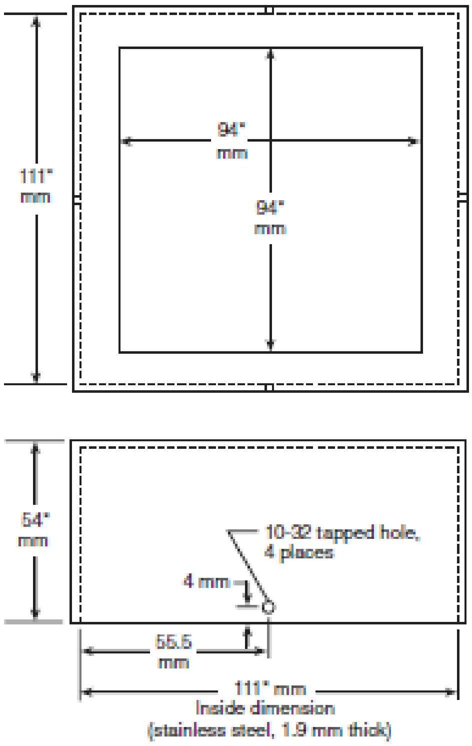



**Figure 9.11 Edge Frame for Cone Calorimeter Tests (Adapted from Babrauskas (2002))**

### 9.3.4 Lack of Record – FASTData's Mass Flow Rate through the Exhaust Duct

From FASTData 1.0 (1999) database's reduced experimental data files there was no mass flow rate through the cone calorimeter's exhaust duct record (Section 3.2.1.1) for similar yield calculation procedures in Chapter 5 to be applied. A consistent yield calculation procedure has been applied to all other tests included in this research work except for the FASTData tests as this procedure requires the actual mass flow rate readings through the exhaust duct (Equation 4.2). Consequently, yields could not be calculated and the reported yields had to be used, which are based on unsmoothed mass records that was reduced by the ASTM E1354 (2010) algorithm. As a result, highly fluctuating yield profiles were produced as shown in Figure 6.3, which also prevent different combustion stages to be identified.

# 10 Recommendations

Recommendations for yield distributions are given in this chapter, along with other recommended improvements to the current methodology and future direction for data acquisition.

## 10.1 Distribution Recommendations

Based on the number of tests involved, the following distributions are recommended and summarised in Table 10.1 to Table 10.4 for design purposes. Not all sub-categories are recommended as some are derived from a limited amount of data involving less than five tests to be statistically representative of the material category they are under. To use the results of these fitted distributions, the users would be relying too much on a limited amount of information. An example would be the two trash container tests performed by Madrzykowski and Kerber (2009) in Section 7.3.4, containing 0.3 kg of flat-folded dry newspaper within a polypropylene trash container. Although it is representative of trash containers of this configuration, not all trash containers are made from polypropylene, containing only dry newspapers. Therefore, to use the fitted distributions derived from these two results alone and apply the results to model any given trash container may under-estimate fire species yields and the heat release from a typical trash container. Nonetheless, results for these individual items based on a less representative test collection are still fitted, and results can be found under individual author groupings.

Material categories that are not recommended for final modelling purposes due to lack of sufficient data are listed below. Despite not include in the final design recommendation, fitted distributions for these items are still available from Appendix A.

- All sub-categories under the “All wallboards” category (three tests only for each material sub-category).
- All items classified as “Other Items” in Section 7.3.4

Only “All stages” results are shown in the sections below for the material categories recommended for design. This is probably the most commonly used stage division as most items would progress from the initial growth stage through the transit stage and into the final smouldering stage.

Where finer analysis requiring distribution parameters for a specific combustion stage, these combustion stages are also fitted with distributions and can be found from Appendix A for the growth (G), transition (T), smouldering (S), and transition and smouldering (TS) stages. The “Broad Material Categories” results can be found from Appendix A.11, where results are grouped across different authors and scales of test. For different combustion stage results for “Finer Material Sub-Categories”, these can be found under individual author groupings. For example, “Domestic Furniture Foams (non-fire retarded)” results can be found from Appendix A.10 for all tests results conducted by Hill (2003).

In addition to the broad material categories described in Section 7.3, some finer material categories are also included below as sufficient number of test is available. Having a large number of tests means that the fitted distributions are now statistically representative for their material categories.

**Table 10.1 Fitted $CO_2$ Yield Distribution Results (All stages)**

| Material Category | Number of Samples | Fitted Distribution | Alpha (α) | Beta (β) | Mean (μ) | Std Dev. (σ) |
|---|---|---|---|---|---|---|
| **Broad Material Categories** | | | | | | |
| All Carpet Tests | 47 | Weibull | 1.59 | 2.12 | 1.90 | 1.22 |
| All Furniture Tests containing Non-Fire Retarded PU Foams | 46 | Gamma | 10.62 | 0.17 | 1.77 | 0.54 |
| All Furniture Tests containing Fire Retarded PU Foams | 19 | Weibull | 3.84 | 1.96 | 1.77 | 0.52 |
| All Tests containing Non-Fire Retarded PU Foams | 66 | Gamma | 6.81 | 0.27 | 1.81 | 0.69 |
| All Tests containing Fire Retarded PU Foams | 33 | Gamma | 7.05 | 0.26 | 1.85 | 0.70 |
| All Furniture Tests containing PU Foams | 65 | Gamma | 10.59 | 0.17 | 1.77 | 0.55 |
| All Tests containing PU Foams | 99 | Gamma | 6.86 | 0.27 | 1.82 | 0.69 |
| **Finer Material Sub-Categories (from Hill, 2003)** | | | | | | |
| All Tests containing Aviation Foams (fire-retarded) | 15 | Gamma | 15.9 | 0.12 | 1.83 | 0.46 |
| All Tests containing Domestic Furniture Foams (non-fire retarded) | 21 | Gamma | 14.5 | 0.13 | 1.82 | 0.48 |
| **Finer Material Sub-Categories (from FASTData, 1999)** | | | | | | |
| All Tests containing Foam and Fabric Combinations without Barrier | 24 | Gamma | 6.95 | 0.24 | 1.65 | 0.63 |
| All Tests containing Foam and Fabric Combination with Barrier | 104 | Gamma | 2.73 | 0.62 | 1.70 | 1.03 |
| **Finer Material Sub-Categories (from Johnson, 2008)** | | | | | | |
| Nylon Carpet Tests | 11 | Triangle | **Min:** 0<br>**Most Likely:** 1.51<br>**Max:** 4.29 | | 1.94 | 0.89 |
| Polypropylene Carpet Tests | 12 | Lognormal | NA | | 1.80 | 1.48 |
| Wool Carpet Tests | 12 | Weibull | 1.30 | 1.81 | 1.67 | 1.29 |
| Wool and Polypropylene Blended Carpet Tests | 12 | Triangle | **Min:** 0<br>**Most Likely:** 1.02<br>**Max:** 4.90 | | 1.97 | 1.06 |

**Table 10.2 Fitted CO Yield Distribution Results (All stages)**

| Material Category | Number of Samples | Fitted Distribution | Alpha (α) | Beta (β) | Mean (μ) | Std Dev. (σ) |
|---|---|---|---|---|---|---|
| **Broad Material Categories** | | | | | | |
| All Carpet Tests | 44 | Weibull | 2.14 | 0.077 | 0.068 | 0.034 |
| All Furniture Tests containing Non-Fire Retarded PU Foams | 46 | Gamma | 1.51 | 0.016 | 0.024 | 0.020 |
| All Furniture Tests containing Fire Retarded PU Foams | 19 | Lognorm | NA | | 0.020 | 0.016 |
| All Tests containing Non-Fire Retarded PU Foams | 66 | Gamma | 1.38 | 0.019 | 0.026 | 0.022 |
| All Tests containing Fire Retarded PU Foams | 33 | Gamma | 1.91 | 0.0098 | 0.019 | 0.014 |
| All Furniture Tests containing PU Foams | 49 | Gamma | 1.61 | 0.014 | 0.023 | 0.018 |
| All Tests containing PU Foams | 99 | Gamma | 1.44 | 0.017 | 0.024 | 0.020 |
| **Finer Material Sub-Categories (from Hill, 2003)** | | | | | | |
| All Tests containing Aviation Foams (fire-retarded) | 15 | Gamma | 2.79 | 0.0067 | 0.019 | 0.011 |
| All Tests containing Domestic Furniture Foams (non-fire retarded) | 21 | Lognorm | NA | | 0.021 | 0.024 |
| **Finer Material Sub-Categories (from FASTData, 1999)** | | | | | | |
| All Tests containing Foam and Fabric Combinations without Barrier | 24 | Gamma | 1.67 | 0.024 | 0.040 | 0.031 |
| All Tests containing Foam and Fabric Combination with Barrier | 104 | Gamma | 1.13 | 0.032 | 0.036 | 0.034 |
| **Finer Material Sub-Categories (from Johnson, 2008)** | | | | | | |
| Nylon Carpet Tests | 11 | Weibull | 2.55 | 0.088 | 0.078 | 0.033 |
| Polypropylene Carpet Tests | 12 | Gamma | 5.91 | 0.0091 | 0.054 | 0.022 |
| Wool Carpet Tests | 12 | Uniform | **Min:** 0<br>**Max:** 0.13 | | 0.065 | 0.037 |
| Wool and Polypropylene Blended Carpet Tests | 12 | Triangle | **Min:** 0<br>**Most Likely:** 0.085<br>**Max:** 0.13 | | 0.072 | 0.027 |

**Table 10.3 Fitted Heat of Combustion Distribution Results (All stages)**

| Material Category | Number of Samples | Fitted Distribution | Alpha (α) | Beta (β) | Mean (μ) | Std Dev. (σ) |
|---|---|---|---|---|---|---|
| **Broad Material Categories** | | | | | | |
| All Wallboard Tests | 38 | Gamma | 3.70 | 3.60 | 13.3 | 6.93 |
| All Carpet Tests | 47 | Weibull | 1.16 | 16.7 | 15.8 | 13.7 |
| All Furniture Tests containing Non-Fire Retarded PU Foams | 46 | Gamma | 12.10 | 1.41 | 17.05 | 4.90 |
| All Furniture Tests containing Fire Retarded PU Foams | 19 | Gamma | 13.49 | 1.26 | 17.02 | 4.63 |
| All Tests containing Non-Fire Retarded PU Foams | 66 | Gamma | 6.77 | 2.70 | 18.3 | 7.03 |
| All Tests containing Fire Retarded PU Foams | 33 | Gamma | 6.24 | 2.91 | 18.2 | 7.28 |
| All Furniture Tests containing PU Foams | 65 | Gamma | 12.39 | 1.38 | 17.04 | 4.84 |
| All Tests containing PU Foams | 99 | Gamma | 6.65 | 2.75 | 18.3 | 7.09 |
| **Finer Material Sub-Categories (from Hill, 2003)** | | | | | | |
| All Tests containing Aviation Foams (fire-retarded) | 15 | Lognormal | NA | | 17.6 | 4.81 |
| All Tests containing Domestic Furniture Foams (non-fire retarded) | 21 | Gamma | 9.50 | 1.82 | 17.3 | 5.61 |
| **Finer Material Sub-Categories (from FASTData, 1999)** | | | | | | |
| All Tests containing Foam and Fabric Combinations without Barrier | 24 | Weibull | 3.86 | 22.5 | 20.3 | 5.88 |
| All Tests containing Foam and Fabric Combination with Barrier | 104 | Triangle | **Min:** 0<br>**Most Likely:** 24.6<br>**Max:** 39.7 | | 21.5 | 8.19 |
| **Finer Material Sub-Categories (from Johnson, 2008)** | | | | | | |
| Nylon Carpet Tests | 11 | Uniform | **Min:** 0<br>**Max:** 32.37 | | 16.2 | 9.34 |
| Polypropylene Carpet Tests | 12 | Lognormal | NA | | 16.8 | 27.0 |
| Wool Carpet Tests | 12 | Triangle | **Min:** 0<br>**Most Likely:** 0.021<br>**Max:** 55.8 | | 18.6 | 13.1 |
| Wool and Polypropylene Blended Carpet Tests | 12 | Triangle | **Min:** 0<br>**Most Likely:** 0.77<br>**Max:** 50.4 | | 17.0 | 11.8 |

**Table 10.4 Fitted Soot Yield Distribution Results (All stages)**

| Material Category | Number of Samples | Fitted Distribution | Alpha (α) | Beta (β) | Mean (μ) | Std Dev. (σ) |
|---|---|---|---|---|---|---|
| **Broad Material Categories** | | | | | | |
| All Wallboard Tests | 38 | Exponential | NA | 0.040 | 0.040 | 0.040 |
| All <u>Furniture</u> Tests containing Non-Fire Retarded PU Foams | 3 | Lognorm | NA | | 0.018 | 0.0032 |
| All Tests containing Non-Fire Retarded PU Foams | 14 | Weibull | 1.67 | 0.021 | 0.019 | 0.011 |
| **Finer Material Sub-Categories (from FASTData, 1999)** | | | | | | |
| All Tests containing Foam and Fabric Combinations <u>without</u> Barrier | 24 | Lognormal | NA | | 0.011 | 0.64 |
| All Tests containing Foam and Fabric Combination <u>with</u> Barrier | 104 | Exponential | NA | 0.0313 | 0.0313 | 0.0313 |

Only tests containing non-fire retarded polyurethane foams have soot yield data. Therefore, the "All Tests containing PU foams" category is only replicating the fit results from the "All Tests containing Non-Fire retarded polyurethane foams". In this case, the fitted soot yield results for the "All Tests containing PU foams" category should not be used as they are only relying on results from one of its sub-categories, giving biased results that could lead to either under- or over-estimations.

## 10.2 Recommendations on Distribution Characteristics (Re-Fitting with Non-Truncated Distributions)

Currently, only non-truncated distributions with a minimum of 0 have been considered. This decision was made to reduce statistical requirements on the simulation models when inputting fire species yields as distributions. However, this limitation has also excluded some distributions from being used as possible fits.

To overcome this, re-fitting all data using truncated distributions can be considered (minimum value of 0). Conversely, the simulation model must also have additional statistical capabilities to support these truncated distribution inputs.

## 10.3 Recommended Further Work

Apart from design value recommendations and recommended improvements on distribution characteristics, future recommended work is also briefly discussed in this section.

### 10.3.1 Additional Measurements on Soot and HCN

Greater emphases should be placed on soot and HCN measurements in all future tests to provide a more complete data. Most tests included in this database did not have soot yield measurements. Consequently, soot yield distribution recommendations are limited to only a few categories (Section 10.1). HCN yields were initially one of the fire species yields to be analysed. However, the only source on HCN production was found from tube furnace tests that could not be used in this research (Sections 3.4 and 5.6).

### 10.3.2 Verifying Secondary Material Contributions

Some preliminary carbon balancing has been done on five of the materials collected in this research (Section 8.1.1). These materials were chosen as their chemical compositions are known from in literature (Tewarson, 2002), so that the amount of carbon lost during combustion could be derived. However, the carpet tests are made up by weaving the surface fibre onto the backing fibre. Not knowing the mass contribution and chemical formula for the backing fibre, the carbon retrieval percentage for carpets in Table 8.5 is slightly lower than the polyurethane foams, which did not have any fabric covering.

In this research, it was initially assumed that the backing fibre would not significantly affect the final yield outcomes. Nonetheless, the exact mass proportion of the surface fibre and the backing fibre should be determined to verify that the surface fibres are indeed the dominant material. If the backing fibre is later found to have a greater mass proportion, all carpet tests should be grouped together under a single “carpet” category, and be compared against other carpet samples in the literature, instead of polypropylene, nylon and wool sample. It was later discovered from species yield comparisons in Section 9.3.1 that considerable discrepancies against literature values exist. Consequently, further investigation into the causes of these discrepancies is required, including verifying the backing fibre contribution.

### 10.3.3 Inclusion of other Interior Furnishing Items

During the initial data acquisition, it was found that a significant emphasis has been placed on upholstered furniture. Experimental results on other interior furnishing items are comparatively much less. Test results that satisfy the requirements of this research (time series records on all essential parameters discussed in Section 3.1) further reduce the number of tests that can be used for distribution fitting in this research. Consequently, a data gap has been observed for interior furnishing items such as televisions, bookcases, wardrobes, and drapes and curtains.

Where possible, further research should be conducted to investigate the fire hazard contributions from these items, in order to fully encompass all potential fire hazards from a typical combustion environment.

# 11 Conclusion

Based on literature comparisons with considerations of the number of tests included in each material categories, design recommendations are made for several items on the $CO_2$ yield, CO yield, soot yield, and heat of combustion. Where possible, each material category is further sub-divided into finer combustion stages according to the schematic stage division diagram in Figure 6.1 and Figures 6.2 a), b) and c) for closer examination and comparisons.

To reduce unrealistically high yields, measurements with mass loss rates below a specified threshold are not included into the final analysis as physical limits exist for every material, governed by chemical reactions (stoichiometry) and influenced by the external factors such as the availability of oxygen and flame temperature. Maximum possible yields for some materials have been sourced from the SFPE Handbook (2002) to provide an estimated upper yield limit in Chapters 8 and 9.

Tube furnace results have been made available during this research; however, no mass records were available for yield calculation to proceed. Although the device was designed to achieve a constant mass loss rate, the nature of the yield calculations is very sensitive to fluctuations in any readings. Therefore, until the constant mass loss rate assumption can be verified, tube furnace results could not be included into the final analysis.

In general, comparisons against literature values have verified the validity of this research results. Some discrepancies still exist due to different reasons discussed in Section 9.3. Care must be taken that the items are in fact comparable by examining the fuel package characteristics and mean values of their combustion yields and the heat of combustions. The greatest discrepancies are observed in CO yields and soot yields, as fire species with a much lower production rate are more difficult to measure.

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# Appendix A Fitted Distribution Results

## Individual Author Grouping (from the same data source)

### Appendix A.1 Wallboards (Collier, Whiting and Wade)

100% Modified Polyester Wall Covering on 13mm Plasterboard
100% Polyester Wall Covering on 13mm Plasterboard
4.7mm Glazed Fibre-Cement Board
Synthetic Mass Loaded Noise Barrier on 13mm Plasterboard
4.75mm Plastic Co-Polymer Wall Lining
9mm Plywood
13mm Softboard
13mm Softboard and Paint
Vinyl Wallpaper on 10mm plasterboard

All Tests

### Appendix A.2 Wallboards (Bong)

10mm Reconstituted Timber Weatherboard ("Weathertex")

### Appendix A.3 Carpets (Johnson)

Nylon Carpets
Polypropylene Carpets
Wool Carpets
Wool and Polypropylene Blended Carpets (50/50)

All Tests

### Appendix A.4 Foam and Fabric Combinations (NIST FASTData)

Foam and Fabric Combinations without Barriers (Aramid, Woven Glass Fibre, or Knitted Glass Charring Fibre)
Foam and Fabric Combinations with Barriers (Aramid, Woven Glass Fibre, or Knitted Glass Charring Fibre)

Cordura Nylon Fabric (100% or 63%)
Cotton Fabric (100%, 75%, 62% or 60%)
Modacrylic Fabric (75%)
Nylon Fabric (100%)
Polyester Fabric (100%)
Polypropylene (Heavy or Light) (100%)
Vinyl Fabric (100%)

All Tests

**Appendix A.5 Foam and Fabric Combinations (Firestone)**

Standard Foams
High Resilience Foams

No Fabric (Foams Only)
Cotton Fabric
Polypropylene Fabric

All Tests

**Appendix A.6 Mock-up Polyurethane Foam Chairs (Collier and Whiting)**

Purpose-Built Chairs
Real Sofas

All Tests

**Appendix A.7 Interior Furnishing Items (Madrzykowski and Kerber)**

Beds
Sleeper Sofas
Trash Container
Upholstered Chair

All Tests

**Appendix A.8 Foam and Fabric Combinations (Denize)**

Fire-Retarded Foams Chairs
Non Fire-Retarded Foams Chairs

Domestic Foams Chairs
Superior Domestic Foams Chairs
Public Auditorium Foams Chairs

Polypropylene Fabric Chairs
Wool Fabric Chairs

All Tests

**Appendix A.9 Foam and Fabric Combinations (Enright)**

Polyurethane Foams Chairs

**Appendix A.10 Foam and Fabric Combinations (Hill)**

Aviation Foam Chairs
Domestic Furniture Foam Chairs
Other Foam Chairs (Public Auditorium Foams)

Polypropylene Fabric Chairs
Wool Fabric Chairs

All Tests

# Combined Grouping (across different sources of data)

**Appendix A.11 Grouped Analysis**

All Wallboard Tests
All Carpet Tests
All <u>Furniture</u> Tests containing Non Fire-Retarded Polyurethane Foams
All <u>Furniture</u> Tests containing Fire-Retarded Polyurethane Foams
All <u>Furniture</u> Tests containing Polyurethane Foams
All Tests containing Non Fire-Retarded Polyurethane Foams
All Tests containing Fire-Retarded Polyurethane Foams
All Tests containing Polyurethane Foams

# Wallboards - 100% Modified Polyester Wall Covering on 13mm Plasterboard

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Weibull | Lognorm | NA | | **Distrib.** | Lognorm | Gamma | Lognorm | NA | |
| **No. Tests** | 3 | 3 | 3 | NA | | **No. Tests** | 3 | 3 | 3 | NA | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | | **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | | **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 7.3374 | 10.8318 | 6.6034 | | | **Mean** | 0.0298 | 0.0742 | 0.0149 | | |
| **Mode** | 4.9692 | 8.9196 | 4.9022 | | | **Mode** | 0.00122 | 0.0729 | 0.00139 | | |
| **Std Dev.** | 3.9967 | 5.4687 | 3.0952 | | | **Std Dev.** | 0.0814 | 0.0101 | 0.0292 | | |
| **Alpha (α)** | NA | 2.0788 | NA | | | **Alpha (α)** | NA | 54.259 | NA | | |
| **Beta (β)** | NA | 12.229 | NA | | | **Beta (β)** | NA | 0.001368 | NA | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 2.7861 | 2.9299 | 2.8727 | NA | | **5%** | 0.000929 | 0.0585 | 0.000853 | NA | |
| **10%** | 3.3529 | 4.1423 | 3.3776 | | | **10%** | 0.00158 | 0.0617 | 0.00135 | | |
| **25%** | 4.5689 | 6.7157 | 4.4269 | | | **25%** | 0.00383 | 0.0672 | 0.00289 | | |
| **50%** | 6.4435 | 10.2521 | 5.9792 | | | **50%** | 0.0103 | 0.0738 | 0.00675 | | |
| **75%** | 9.0873 | 14.3095 | 8.0758 | | | **75%** | 0.0275 | 0.0808 | 0.0158 | | |
| **90%** | 12.3828 | 18.2653 | 10.5847 | | | **90%** | 0.0667 | 0.0874 | 0.0338 | | |
| **95%** | 14.902 | 20.7303 | 12.445 | | | **95%** | 0.1134 | 0.0916 | 0.0534 | | |

# Wallboards - 100% Polyester Wall Covering on 13mm Plasterboard

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Uniform | Lognorm | NA | | **Distrib.** | Lognorm | Gamma | Lognorm | NA | |
| **No. Tests** | 3 | 3 | 3 | NA | | **No. Tests** | 3 | 3 | 3 | NA | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | | **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | 27.346 | +Inf | | | **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 7.5092 | 13.673 | 5.699 | | | **Mean** | 0.0156 | 0.0406 | 0.00718 | | |
| **Mode** | 3.3817 | 0 | 3.6281 | | | **Mode** | 0.00342 | 0.0393 | 0.00386 | | |
| **Std Dev.** | 6.2918 | 7.8941 | 3.3778 | | | **Std Dev.** | 0.0206 | 0.00729 | 0.00514 | | |
| **Alpha (α)** | NA | NA | NA | | | **Alpha (α)** | NA | 31.096 | NA | | |
| **Beta (β)** | NA | NA | NA | | | **Beta (β)** | NA | 0.00131 | NA | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 1.7344 | 1.3673 | 1.9882 | NA | | **5%** | 0.0018 | 0.0294 | 0.00202 | NA | |
| **10%** | 2.2606 | 2.7346 | 2.4268 | | | **10%** | 0.00259 | 0.0316 | 0.00256 | | |
| **25%** | 3.5196 | 6.8365 | 3.3861 | | | **25%** | 0.00477 | 0.0355 | 0.00378 | | |
| **50%** | 5.7559 | 13.673 | 4.9026 | | | **50%** | 0.00941 | 0.0402 | 0.00584 | | |
| **75%** | 9.4131 | 20.5095 | 7.0983 | | | **75%** | 0.0185 | 0.0453 | 0.00901 | | |
| **90%** | 14.6554 | 24.6114 | 9.904 | | | **90%** | 0.0341 | 0.0502 | 0.0133 | | |
| **95%** | 19.1012 | 25.9787 | 12.0888 | | | **95%** | 0.0492 | 0.0533 | 0.0168 | | |

# Wallboards - Glazed Fibre-Cement Board

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Weibull | Lognorm | NA | | **Distrib.** | Lognorm | Gamma | Lognorm | NA | |
| **No. Tests** | 3 | 3 | 3 | NA | | **No. Tests** | 3 | 3 | 3 | NA | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | | **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | | **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 8.5579 | 11.7053 | 6.5646 | | | **Mean** | 0.021 | 0.0354 | 0.0126 | | |
| **Mode** | 4.493 | 8.4953 | 4.3466 | | | **Mode** | 0.0111 | 0.0299 | 0.00968 | | |
| **Std Dev.** | 6.2688 | 6.6637 | 3.6923 | | | **Std Dev.** | 0.0153 | 0.0139 | 0.00555 | | |
| **Alpha (α)** | NA | 1.8195 | NA | | | **Alpha (α)** | NA | 6.4397 | NA | | |
| **Beta (β)** | NA | 13.169 | NA | | | **Beta (β)** | NA | 0.005496 | NA | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 2.3491 | 2.574 | 2.4155 | NA | | **5%** | 0.00579 | 0.016 | 0.00578 | NA | |
| **10%** | 2.9807 | 3.8232 | 2.9223 | | | **10%** | 0.00734 | 0.0191 | 0.00674 | | |
| **25%** | 4.4372 | 6.6402 | 4.0174 | | | **25%** | 0.0109 | 0.0253 | 0.0087 | | |
| **50%** | 6.9039 | 10.7665 | 5.7216 | | | **50%** | 0.017 | 0.0336 | 0.0116 | | |
| **75%** | 10.7418 | 15.7587 | 8.1488 | | | **75%** | 0.0263 | 0.0435 | 0.0153 | | |
| **90%** | 15.9909 | 20.8272 | 11.2026 | | | **90%** | 0.0392 | 0.054 | 0.0198 | | |
| **95%** | 20.29 | 24.0681 | 13.5531 | | | **95%** | 0.0497 | 0.061 | 0.0231 | | |

# Wallboards - Mass Loaded Noise Barrier on 13mm Plasterboard

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Triangle | Uniform | Triangle | NA | | **Distrib.** | Lognorm | Gamma | Lognorm | NA | |
| **No. Tests** | 3 | 3 | 3 | NA | | **No. Tests** | 3 | 3 | 3 | NA | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | | **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | 45.8522 | 44.4239 | 45.0065 | | | **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 18.7616 | 22.2119 | 18.5816 | | | **Mean** | 0.0264 | 0.091 | 0.0206 | | |
| **Mode** | 10.4326 | 0 | 10.7382 | | | **Mode** | 0.00329 | 0.0749 | 0.00346 | | |
| **Std Dev.** | 9.8119 | 12.8241 | 9.5963 | | | **Std Dev.** | 0.0458 | 0.0382 | 0.0312 | | |
| **Alpha (α)** | NA | NA | NA | | | **Alpha (α)** | NA | 5.665 | NA | | |
| **Beta (β)** | NA | NA | NA | | | **Beta (β)** | NA | 0.016061 | NA | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 4.8906 | 2.2212 | 4.9157 | NA | | **5%** | 0.0019 | 0.0385 | 0.00189 | NA | |
| **10%** | 6.9164 | 4.4424 | 6.9519 | | | **10%** | 0.00291 | 0.0467 | 0.00281 | | |
| **25%** | 10.9516 | 11.106 | 10.9959 | | | **25%** | 0.00596 | 0.0632 | 0.00545 | | |
| **50%** | 17.356 | 22.2119 | 17.237 | | | **50%** | 0.0132 | 0.0857 | 0.0114 | | |
| **75%** | 25.7024 | 33.3179 | 25.3705 | | | **75%** | 0.0292 | 0.1131 | 0.0237 | | |
| **90%** | 33.1083 | 39.9815 | 32.5876 | | | **90%** | 0.0597 | 0.1421 | 0.046 | | |
| **95%** | 36.8409 | 42.2027 | 36.225 | | | **95%** | 0.0917 | 0.1616 | 0.0684 | | |

# Wallboards - Plastic Co-Polymer

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Triangle | Weibull | Triangle | NA | |
| **No. Tests** | 3 | 3 | 3 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | 60.4725 | +Inf | 75.792 | | |
| **Mean** | 30.4093 | 27.6344 | 25.7088 | | |
| **Mode** | 30.7554 | 28.0284 | 1.3343 | | |
| **Std Dev.** | 12.3445 | 8.5036 | 17.7092 | | |
| **Alpha (α)** | NA | 3.6106 | NA | | |
| **Beta (β)** | NA | 30.662 | NA | | |
| **Percentile** | | | | | |
| **5%** | 9.6433 | 13.4691 | 2.5723 | NA | |
| **10%** | 13.6377 | 16.4408 | 4.5251 | | |
| **25%** | 21.563 | 21.7142 | 10.7346 | | |
| **50%** | 30.4947 | 27.7025 | 22.6728 | | |
| **75%** | 39.2766 | 33.5655 | 38.2311 | | |
| **90%** | 47.067 | 38.63 | 52.0364 | | |
| **95%** | 50.9934 | 41.5507 | 58.9943 | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Weibull | Triangle | NA | |
| **No. Tests** | 3 | 3 | 3 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | 0.2307 | | |
| **Mean** | 0.0748 | 0.0633 | 0.0769 | | |
| **Mode** | 0.0225 | 0.0662 | 2.5E-05 | | |
| **Std Dev.** | 0.06 | 0.0117 | 0.0544 | | |
| **Alpha (α)** | 1.2543 | 6.2996 | NA | | |
| **Beta (β)** | 0.080374 | 0.068015 | NA | | |
| **Percentile** | | | | | |
| **5%** | 0.00753 | 0.0424 | 0.00585 | NA | |
| **10%** | 0.0134 | 0.0476 | 0.0119 | | |
| **25%** | 0.0298 | 0.0558 | 0.0309 | | |
| **50%** | 0.06 | 0.0642 | 0.0676 | | |
| **75%** | 0.1043 | 0.0716 | 0.1154 | | |
| **90%** | 0.1563 | 0.0776 | 0.1578 | | |
| **95%** | 0.1928 | 0.081 | 0.1792 | | |

# Wallboards – Plywood

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Lognorm | Triangle | NA | |
| **No. Tests** | 3 | 3 | 3 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | 29.8734 | | |
| **Mean** | 13.3896 | 10.4068 | 19.9156 | | |
| **Mode** | 9.8807 | 9.0248 | 29.8734 | | |
| **Std Dev.** | 6.3453 | 3.2851 | 7.0412 | | |
| **Alpha (α)** | NA | NA | NA | | |
| **Beta (β)** | NA | NA | NA | | |
| **Percentile** | | | | | |
| **5%** | 5.7709 | 5.9776 | 6.6799 | NA | |
| **10%** | 6.7961 | 6.6859 | 9.4468 | | |
| **25%** | 8.9315 | 8.0614 | 14.9367 | | |
| **50%** | 12.0997 | 9.9241 | 21.1237 | | |
| **75%** | 16.3917 | 12.2172 | 25.8711 | | |
| **90%** | 21.5423 | 14.7309 | 28.3404 | | |
| **95%** | 25.3694 | 16.4762 | 29.117 | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Gamma | Lognorm | NA | |
| **No. Tests** | 3 | 3 | 3 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 0.0119 | 0.0127 | 0.0124 | | |
| **Mode** | 0.00185 | 0.00776 | 0.000368 | | |
| **Std Dev.** | 0.0105 | 0.00792 | 0.0382 | | |
| **Alpha (α)** | 1.1317 | 2.5725 | NA | | |
| **Beta (β)** | 0.012402 | 0.00494 | NA | | |
| **Percentile** | | | | | |
| **5%** | 0.000899 | 0.003 | 0.00031 | NA | |
| **10%** | 0.0017 | 0.00418 | 0.00054 | | |
| **25%** | 0.00412 | 0.00688 | 0.00137 | | |
| **50%** | 0.00897 | 0.0111 | 0.00385 | | |
| **75%** | 0.0166 | 0.0168 | 0.0108 | | |
| **90%** | 0.0259 | 0.0233 | 0.0274 | | |
| **95%** | 0.0327 | 0.0279 | 0.0478 | | |

# Wallboards – Softboard

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Weibull | Lognorm | NA | |
| **No. Tests** | 3 | 3 | 3 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 13.3053 | 10.4426 | 13.5051 | | |
| **Mode** | 11.5733 | 10.1758 | 12.7185 | | |
| **Std Dev.** | 4.1532 | 3.8462 | 2.7285 | | |
| **Alpha (α)** | NA | 2.9558 | NA | | |
| **Beta (β)** | NA | 11.702 | NA | | |
| **Percentile** | | | | | |
| **5%** | 7.6916 | 4.2839 | 9.5264 | NA | |
| **10%** | 8.5926 | 5.4651 | 10.2444 | | |
| **25%** | 10.3399 | 7.6769 | 11.567 | | |
| **50%** | 12.7009 | 10.337 | 13.2377 | | |
| **75%** | 15.601 | 13.0689 | 15.1496 | | |
| **90%** | 18.7734 | 15.5165 | 17.1054 | | |
| **95%** | 20.9726 | 16.9613 | 18.3947 | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Gamma | Weibull | NA | |
| **No. Tests** | 3 | 3 | 3 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 0.0085 | 0.01252 | 0.00799 | | |
| **Mode** | 0.00224 | 0.01229 | 0.00126 | | |
| **Std Dev.** | 0.00699 | 0.0017 | 0.00707 | | |
| **Alpha (α)** | 1.221 | 54.431 | 1.1332 | | |
| **Beta (β)** | 0.009071 | 0.000230 | 0.00836 | | |
| **Percentile** | | | | | |
| **5%** | 0.000796 | 0.00986 | 0.000608 | NA | |
| **10%** | 0.00144 | 0.0104 | 0.00115 | | |
| **25%** | 0.00327 | 0.01134 | 0.00278 | | |
| **50%** | 0.00672 | 0.01244 | 0.00605 | | |
| **75%** | 0.0119 | 0.01362 | 0.0112 | | |
| **90%** | 0.018 | 0.01474 | 0.0175 | | |
| **95%** | 0.0223 | 0.01543 | 0.022 | | |

# Wallboards – Softboard and Paint

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Weibull | Lognorm | NA | |
| **No. Tests** | 3 | 3 | 3 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 12.2479 | 10.5027 | 19.08 | | |
| **Mode** | 10.3786 | 10.9594 | 18.9344 | | |
| **Std Dev.** | 4.1846 | 2.2808 | 1.3652 | | |
| **Alpha (α)** | NA | 5.3001 | NA | | |
| **Beta (β)** | NA | 11.4 | NA | | |
| **Percentile** | | | | | |
| **5%** | 6.71 | 6.5094 | 16.9208 | NA | |
| **10%** | 7.571 | 7.4563 | 17.3658 | | |
| **25%** | 9.2631 | 9.0122 | 18.1358 | | |
| **50%** | 11.5901 | 10.6387 | 19.0313 | | |
| **75%** | 14.5017 | 12.1251 | 19.9711 | | |
| **90%** | 17.7428 | 13.3432 | 20.8565 | | |
| **95%** | 20.0193 | 14.0225 | 21.4051 | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Weibull | Lognorm | NA | |
| **No. Tests** | 3 | 3 | 3 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 0.00699 | 0.00547 | 0.0108 | | |
| **Mode** | 0.000659 | 0 | 0.00547 | | |
| **Std Dev.** | 0.0137 | 0.00687 | 0.00824 | | |
| **Alpha (α)** | NA | 0.80229 | NA | | |
| **Beta (β)** | NA | 0.00484 | NA | | |
| **Percentile** | | | | | |
| **5%** | 0.000404 | 0.000119 | 0.00284 | NA | |
| **10%** | 0.000637 | 0.000293 | 0.00363 | | |
| **25%** | 0.00136 | 0.00102 | 0.00548 | | |
| **50%** | 0.00318 | 0.00306 | 0.00863 | | |
| **75%** | 0.00742 | 0.00727 | 0.0136 | | |
| **90%** | 0.0159 | 0.0137 | 0.0205 | | |
| **95%** | 0.0251 | 0.019 | 0.0262 | | |

# Wallboards – Vinyl Wallpaper

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Weibull | Lognorm | NA | | **Distrib.** | Lognorm | Weibull | Lognorm | NA | |
| **No. Tests** | 3 | 3 | 3 | NA | | **No. Tests** | 3 | 3 | 3 | NA | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | | **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | | **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 5.2799 | 9.8697 | 4.5646 | | | **Mean** | 0.0090 | 0.0776 | 0.00202 | | |
| **Mode** | 4.1728 | 10.2289 | 4.0531 | | | **Mode** | 0.00015 | 0.0765 | 0.00054 | | |
| **Std Dev.** | 2.176 | 2.4842 | 1.3107 | | | **Std Dev.** | 0.0342 | 0.0273 | 0.0024 | | |
| **Alpha (α)** | NA | 4.5084 | NA | | | **Alpha (α)** | NA | 3.1055 | NA | | |
| **Beta (β)** | NA | 10.814 | NA | | | **Beta (β)** | NA | 0.086749 | NA | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 2.5446 | 5.5959 | 2.7613 | NA | | **5%** | 0.00015 | 0.0333 | 0.00028 | NA | |
| **10%** | 2.9384 | 6.5646 | 3.0587 | | | **10%** | 0.00028 | 0.042 | 0.00039 | | |
| **25%** | 3.7371 | 8.203 | 3.6286 | | | **25%** | 0.00075 | 0.0581 | 0.00069 | | |
| **50%** | 4.8816 | 9.9697 | 4.3873 | | | **50%** | 0.00229 | 0.0771 | 0.0013 | | |
| **75%** | 6.3765 | 11.6266 | 5.3046 | | | **75%** | 0.00698 | 0.0964 | 0.00244 | | |
| **90%** | 8.1098 | 13.0116 | 6.2931 | | | **90%** | 0.0191 | 0.1135 | 0.00432 | | |
| **95%** | 9.3649 | 13.7937 | 6.9707 | | | **95%** | 0.0348 | 0.1235 | 0.00608 | | |

# Wallboards – All Tests

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Lognorm | Lognorm | NA | | **Distrib.** | Lognorm | Weibull | Lognorm | NA | |
| **No. Tests** | | | | NA | | **No. Tests** | | | | NA | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | | **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | | **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 13.7927 | 13.8841 | 13.8204 | | | **Mean** | 0.0267 | 0.0304 | 0.0193 | | |
| **Mode** | 6.1694 | 8.12 | 5.5394 | | | **Mode** | 0.00080 | 0 | 0.00078 | | |
| **Std Dev.** | 11.62 | 9.1034 | 12.6629 | | | **Std Dev.** | 0.0817 | 0.0382 | 0.0527 | | |
| **Alpha (α)** | NA | NA | NA | | | **Alpha (α)** | NA | 0.803 | NA | | |
| **Beta (β)** | NA | NA | NA | | | **Beta (β)** | NA | 0.02691 | NA | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 3.1624 | 4.3419 | 2.8214 | NA | | **5%** | 0.00067 | 0.00067 | 0.00060 | NA | |
| **10%** | 4.1263 | 5.3955 | 3.7467 | | | **10%** | 0.00116 | 0.00163 | 0.00102 | | |
| **25%** | 6.4365 | 7.757 | 6.0184 | | | **25%** | 0.00295 | 0.0057 | 0.00247 | | |
| **50%** | 10.5482 | 11.6108 | 10.1899 | | | **50%** | 0.00828 | 0.0171 | 0.00662 | | |
| **75%** | 17.2866 | 17.3794 | 17.2527 | | | **75%** | 0.0232 | 0.0404 | 0.0178 | | |
| **90%** | 26.9645 | 24.9858 | 27.7132 | | | **90%** | 0.0588 | 0.076 | 0.0431 | | |
| **95%** | 35.184 | 31.0489 | 36.8015 | | | **95%** | 0.1025 | 0.1055 | 0.0734 | | |

# Wallboards – 10mm Reconstituted Timber Weatherboard ("Weathertex")

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Weibull | Gamma | NA | |
| **No. Tests** | 11 | 11 | 11 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 12.940 | 11.153 | 16.329 | | |
| **Mode** | 13.076 | 11.596 | 15.622 | | |
| **Std Dev.** | 4.0719 | 2.659 | 3.398 | | |
| **Alpha (α)** | 3.522 | 4.786 | 23.093 | | |
| **Beta (β)** | 14.377 | 12.178 | 0.7071 | | |
| **Percentile** | | | | | |
| **5%** | 6.186 | 6.547 | 11.170 | NA | |
| **10%** | 7.5887 | 7.610 | 12.154 | | |
| **25%** | 10.093 | 9.387 | 13.927 | | |
| **50%** | 12.956 | 11.280 | 16.094 | | |
| **75%** | 15.774 | 13.038 | 18.475 | | |
| **90%** | 18.218 | 14.497 | 20.807 | | |
| **95%** | 19.632 | 15.316 | 22.290 | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Weibull | Weibull | NA | |
| **No. Tests** | 11 | 11 | 11 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 0.0496 | 0.0287 | 0.0936 | | |
| **Mode** | 0.0287 | 0.0299 | 0.0802 | | |
| **Std Dev.** | 0.0329 | 0.004 | 0.045 | | |
| **Alpha (α)** | NA | 8.5355 | 2.1988 | | |
| **Beta (β)** | NA | 0.0303 | 0.1057 | | |
| **Percentile** | | | | | |
| **5%** | 0.0153 | 0.0214 | 0.0274 | NA | |
| **10%** | 0.0191 | 0.0233 | 0.038 | | |
| **25%** | 0.0275 | 0.0262 | 0.06 | | |
| **50%** | 0.0414 | 0.0291 | 0.0895 | | |
| **75%** | 0.0621 | 0.0315 | 0.1227 | | |
| **90%** | 0.0897 | 0.0334 | 0.1545 | | |
| **95%** | 0.1116 | 0.0345 | 0.1741 | | |

# Carpets – Nylon

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Triangle | Lognorm | Triangle | Lognorm | Lognorm |
| **No. Tests** | 11 | 11 | 11 | 11 | 11 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | 4.2948 | +Inf | 4.1888 | +Inf | +Inf |
| **Mean** | 1.935 | 0.7983 | 2.2782 | 2.8766 | 1.825 |
| **Mode** | 1.5101 | 0.3513 | 2.6458 | 2.7869 | 1.461 |
| **Std Dev.** | 0.8895 | 0.6813 | 0.8649 | 0.4204 | 0.7297 |
| **Alpha (α)** | NA | NA | NA | NA | NA |
| **Beta (β)** | NA | NA | NA | NA | NA |
| **Percentile** | | | | | |
| **5%** | 0.5695 | 0.1799 | 0.7444 | 2.241 | 0.8994 |
| **10%** | 0.8053 | 0.2353 | 1.0527 | 2.3626 | 1.0345 |
| **25%** | 1.2733 | 0.3687 | 1.6645 | 2.5805 | 1.3069 |
| **50%** | 1.8494 | 0.6072 | 2.354 | 2.8464 | 1.6946 |
| **75%** | 2.5657 | 1.0001 | 2.9177 | 3.1396 | 2.1972 |
| **90%** | 3.2012 | 1.567 | 3.3849 | 3.4293 | 2.7759 |
| **95%** | 3.5215 | 2.0501 | 3.6203 | 3.6153 | 3.1927 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Gamma | Weibull | Lognorm | Lognorm |
| **No. Tests** | 11 | 11 | 11 | 11 | 11 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 0.0784 | 0.0283 | 0.0862 | 0.0673 | 0.1003 |
| **Mode** | 0.0727 | 0.0232 | 0.086 | 0.0576 | 0.093 |
| **Std Dev.** | 0.0329 | 0.0119 | 0.0289 | 0.0224 | 0.0229 |
| **Alpha (α)** | 2.5517 | 5.6223 | 3.280 | NA | NA |
| **Beta (β)** | 0.0883 | 0.00503 | 0.0961 | NA | NA |
| **Percentile** | | | | | |
| **5%** | 0.0276 | 0.0119 | 0.0389 | 0.0375 | 0.0675 |
| **10%** | 0.0366 | 0.0145 | 0.0484 | 0.0422 | 0.0733 |
| **25%** | 0.0542 | 0.0196 | 0.0657 | 0.0514 | 0.084 |
| **50%** | 0.0765 | 0.0266 | 0.0859 | 0.0639 | 0.0978 |
| **75%** | 0.1004 | 0.0351 | 0.1062 | 0.0795 | 0.1138 |
| **90%** | 0.1224 | 0.0442 | 0.1239 | 0.0967 | 0.1305 |
| **95%** | 0.1357 | 0.0503 | 0.1343 | 0.1088 | 0.1416 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Uniform | Weibull | Triangle | Lognorm | Triangle |
| **No. Tests** | 11 | 11 | 11 | 11 | 11 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | 32.367 | +Inf | 32.6086 | +Inf | 30.4850 |
| **Mean** | 16.184 | 7.4137 | 17.8213 | 22.5888 | 12.1342 |
| **Mode** | 0 | 0 | 20.8553 | 21.8802 | 5.9175 |
| **Std Dev.** | 9.3436 | 9.0835 | 6.7421 | 3.3103 | 6.5995 |
| **Alpha (α)** | NA | 0.82141 | NA | NA | NA |
| **Beta (β)** | NA | 6.6647 | NA | NA | NA |
| **Percentile** | | | | | |
| **5%** | 1.6184 | 0.1792 | 5.8312 | 17.5854 | 3.0033 |
| **10%** | 3.2367 | 0.4305 | 8.2466 | 18.5417 | 4.2473 |
| **25%** | 8.0918 | 1.4624 | 13.039 | 20.2573 | 6.7847 |
| **50%** | 16.184 | 4.2658 | 18.4399 | 22.3501 | 11.1337 |
| **75%** | 24.275 | 9.9192 | 22.8201 | 24.6592 | 16.8015 |
| **90%** | 29.131 | 18.397 | 26.4178 | 26.9407 | 21.8307 |
| **95%** | 30.749 | 25.3444 | 28.2311 | 28.4059 | 24.3654 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min.** | NA | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev.** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Carpets – Polypropylene

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Weibull | Lognorm | NA | |
| **No. Tests** | 12 | 12 | 12 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 1.7973 | 1.8007 | 1.7511 | | |
| **Mode** | 0.83 | 0.587 | 0.979 | | |
| **Std Dev.** | 1.4753 | 1.4205 | 1.2049 | | |
| **Alpha (α)** | NA | 1.277 | NA | | |
| **Beta (β)** | NA | 1.9425 | NA | | |
| **Percentile** | | | | | |
| **5%** | 0.4266 | 0.1898 | 0.5181 | NA | |
| **10%** | 0.5537 | 0.3335 | 0.6495 | | |
| **25%** | 0.8561 | 0.7322 | 0.9479 | | |
| **50%** | 1.3892 | 1.4579 | 1.4426 | | |
| **75%** | 2.2542 | 2.5087 | 2.1954 | | |
| **90%** | 3.4851 | 3.7325 | 3.2037 | | |
| **95%** | 4.5234 | 4.5867 | 4.0169 | | |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Gamma | Gamma | NA | |
| **No. Tests** | 12 | 12 | 12 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 0.0541 | 0.0401 | 0.063 | | |
| **Mode** | 0.0449 | 0.0341 | 0.0561 | | |
| **Std Dev.** | 0.0222 | 0.0155 | 0.0207 | | |
| **Alpha (α)** | 5.9146 | 6.6805 | 9.2198 | | |
| **Beta (β)** | 0.00914 | 0.00600 | 0.00683 | | |
| **Percentile** | | | | | |
| **5%** | 0.0234 | 0.0184 | 0.0332 | NA | |
| **10%** | 0.0282 | 0.0219 | 0.0383 | | |
| **25%** | 0.0379 | 0.0288 | 0.048 | | |
| **50%** | 0.051 | 0.0381 | 0.0607 | | |
| **75%** | 0.067 | 0.0491 | 0.0754 | | |
| **90%** | 0.0838 | 0.0607 | 0.0906 | | |
| **95%** | 0.095 | 0.0685 | 0.1005 | | |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Weibull | Lognorm | NA | |
| **No. Tests** | 12 | 12 | 12 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 16.780 | 24.278 | 12.306 | | |
| **Mode** | 2.4775 | 3.972 | 2.8412 | | |
| **Std Dev.** | 26.951 | 21.388 | 15.841 | | |
| **Alpha (α)** | NA | 1.1376 | NA | | |
| **Beta (β)** | NA | 25.428 | NA | | |
| **Percentile** | | | | | |
| **5%** | 1.384 | 1.8683 | 1.485 | NA | |
| **10%** | 2.0861 | 3.5175 | 2.1267 | | |
| **25%** | 4.1406 | 8.5054 | 3.8755 | | |
| **50%** | 8.8687 | 18.4248 | 7.5492 | | |
| **75%** | 18.996 | 33.8855 | 14.705 | | |
| **90%** | 37.704 | 52.932 | 26.798 | | |
| **95%** | 56.829 | 66.708 | 38.377 | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min.** | NA | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev.** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Carpets – Wool

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Weibull | Weibull | Triangle | Uniform | Lognorm |
| No. Tests | 12 | 12 | 12 | 12 | 6 |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | 0 | 0 |
| Max. | +Inf | +Inf | 4.9693 | 4.8342 | +Inf |
| Mean | 1.6714 | 1.3804 | 1.6579 | 2.4171 | 1.5007 |
| Mode | 0.5919 | 0.9581 | 0.00441 | 0 | 1.3369 |
| Std Dev. | 1.2932 | 0.8123 | 1.1708 | 1.3955 | 0.4247 |
| Alpha (α) | 1.3035 | 1.7542 | NA | NA | NA |
| Beta (β) | 1.8106 | 1.5502 | NA | NA | NA |
| Percentile | | | | | |
| 5% | 0.1854 | 0.2851 | 0.128 | 0.2417 | 0.9147 |
| 10% | 0.3221 | 0.4298 | 0.2571 | 0.4834 | 1.0118 |
| 25% | 0.6962 | 0.762 | 0.6677 | 1.2085 | 1.1974 |
| 50% | 1.3668 | 1.2579 | 1.457 | 2.4171 | 1.444 |
| 75% | 2.3262 | 1.8675 | 2.4858 | 3.6256 | 1.7413 |
| 90% | 3.4333 | 2.4939 | 3.3986 | 4.3507 | 2.0608 |
| 95% | 4.2013 | 2.8975 | 3.8586 | 4.5924 | 2.2795 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Uniform | Gamma | Uniform | Uniform | Lognorm |
| No. Tests | 9 | 9 | 9 | 9 | 6 |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | 0 | 0 |
| Max. | 0.1293 | +Inf | 0.1293 | 0.1077 | +Inf |
| Mean | 0.0647 | 0.0265 | 0.0647 | 0.0539 | 0.1003 |
| Mode | 0 | 0.0186 | 0 | 0 | 0.0977 |
| Std Dev. | 0.0373 | 0.0145 | 0.0373 | 0.0311 | 0.0134 |
| Alpha (α) | NA | 3.3599 | NA | NA | NA |
| Beta (β) | NA | 0.00790 | NA | NA | NA |
| Percentile | | | | | |
| 5% | 0.00647 | 0.00795 | 0.00647 | 0.00539 | 0.0798 |
| 10% | 0.0129 | 0.0105 | 0.0129 | 0.0108 | 0.0838 |
| 25% | 0.0323 | 0.0159 | 0.0323 | 0.0269 | 0.0909 |
| 50% | 0.0647 | 0.0239 | 0.0647 | 0.0539 | 0.0994 |
| 75% | 0.097 | 0.0344 | 0.097 | 0.0808 | 0.1088 |
| 90% | 0.1164 | 0.0459 | 0.1164 | 0.097 | 0.118 |
| 95% | 0.1228 | 0.0539 | 0.1229 | 0.1024 | 0.1238 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Triangle | Weibull | Triangle | Triangle | Uniform |
| No. Tests | 12 | 12 | 12 | 12 | 6 |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | 0 | 0 |
| Max. | 55.759 | +Inf | 44.394 | 46.302 | 44.008 |
| Mean | 18.593 | 15.446 | 14.805 | 15.441 | 22.004 |
| Mode | 0.0207 | 9.332 | 0.0207 | 0.0207 | 0 |
| Std Dev. | 13.140 | 9.884 | 10.461 | 10.911 | 12.704 |
| Alpha (α) | NA | 1.600 | NA | NA | NA |
| Beta (β) | NA | 17.228 | NA | NA | NA |
| Percentile | | | | | |
| 5% | 1.4219 | 2.6915 | 1.134 | 1.1825 | 2.2004 |
| 10% | 2.8712 | 4.2207 | 2.288 | 2.3859 | 4.401 |
| 25% | 7.4793 | 7.9075 | 5.957 | 6.2123 | 11.002 |
| 50% | 16.339 | 13.701 | 13.010 | 13.569 | 22.004 |
| 75% | 27.885 | 21.130 | 22.202 | 23.156 | 33.006 |
| 90% | 38.130 | 29.015 | 30.358 | 31.663 | 39.607 |
| 95% | 43.294 | 34.203 | 34.469 | 35.951 | 41.807 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | NA | | | | |
| No. Tests | NA | | | | |
| Parameter | | | | | |
| Min. | NA | | | | |
| Max. | | | | | |
| Mean | | | | | |
| Mode | | | | | |
| Std Dev. | | | | | |
| Alpha (α) | | | | | |
| Beta (β) | | | | | |
| Percentile | | | | | |
| 5% | NA | | | | |
| 10% | | | | | |
| 25% | | | | | |
| 50% | | | | | |
| 75% | | | | | |
| 90% | | | | | |
| 95% | | | | | |

# Carpets – 50% Wool and 50% Polypropylene

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Triangle | Lognorm | Triangle | Gamma | Lognorm |
| **No. Tests** | 12 | 12 | 12 | 12 | 10 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | 4.9023 | +Inf | 4.9966 | +Inf | +Inf |
| **Mean** | 1.9726 | 1.3061 | 2.0842 | 3.0519 | 1.5195 |
| **Mode** | 1.0154 | 0.5512 | 1.2559 | 2.8993 | 1.2025 |
| **Std Dev.** | 1.0563 | 1.0524 | 1.0611 | 0.6823 | 0.6243 |
| **Alpha (α)** | NA | NA | NA | 20.008 | NA |
| **Beta (β)** | NA | NA | NA | 0.1525 | NA |
| **Percentile** | | | | | |
| **5%** | 0.4989 | 0.3224 | 0.5602 | 2.0228 | 0.734 |
| **10%** | 0.7055 | 0.4047 | 0.7922 | 2.2166 | 0.8473 |
| **25%** | 1.1219 | 0.6093 | 1.2525 | 2.5683 | 1.0768 |
| **50%** | 1.8157 | 0.9938 | 1.9396 | 3.0012 | 1.4055 |
| **75%** | 2.7197 | 1.6504 | 2.835 | 3.4803 | 1.8346 |
| **90%** | 3.5219 | 2.5893 | 3.6295 | 3.9524 | 2.3316 |
| **95%** | 3.9262 | 3.3545 | 4.0299 | 4.2539 | 2.6914 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Triangle | Lognorm | Weibull | Triangle | Gamma |
| **No. Tests** | 12 | 12 | 12 | 12 | 10 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | 0.1326 | +Inf | +Inf | 0.108 | +Inf |
| **Mean** | 0.0724 | 0.0322 | 0.0844 | 0.0678 | 0.097 |
| **Mode** | 0.0845 | 0.026 | 0.0878 | 0.0954 | 0.0959 |
| **Std Dev.** | 0.0274 | 0.0127 | 0.0195 | 0.0241 | 0.0107 |
| **Alpha (α)** | NA | NA | 4.9637 | NA | 82.59 |
| **Beta (β)** | NA | NA | 0.0919 | NA | 0.00117 |
| **Percentile** | | | | | |
| **5%** | 0.0237 | 0.0161 | 0.0505 | 0.0227 | 0.0802 |
| **10%** | 0.0335 | 0.0185 | 0.0584 | 0.0321 | 0.0836 |
| **25%** | 0.0529 | 0.0232 | 0.0715 | 0.0508 | 0.0896 |
| **50%** | 0.0749 | 0.03 | 0.0854 | 0.0718 | 0.0966 |
| **75%** | 0.0927 | 0.0387 | 0.0982 | 0.0879 | 0.104 |
| **90%** | 0.1074 | 0.0487 | 0.1087 | 0.0964 | 0.1109 |
| **95%** | 0.1148 | 0.0559 | 0.1147 | 0.0998 | 0.1152 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Triangle | Triangle | Triangle | Weibull | Lognorm |
| **No. Tests** | 12 | 12 | 12 | 12 | 10 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | 50.379 | 50.019 | 50.374 | +Inf | +Inf |
| **Mean** | 17.049 | 16.849 | 17.254 | 28.285 | 9.568 |
| **Mode** | 0.7665 | 0.5284 | 1.388 | 29.001 | 2.744 |
| **Std Dev.** | 11.785 | 11.728 | 11.713 | 8.0301 | 10.908 |
| **Alpha (α)** | NA | NA | NA | 3.9477 | NA |
| **Beta (β)** | NA | NA | NA | 31.229 | NA |
| **Percentile** | | | | | |
| **5%** | 1.6506 | 1.5247 | 1.9564 | 14.716 | 1.407 |
| **10%** | 2.9503 | 2.8181 | 3.2478 | 17.6607 | 1.960 |
| **25%** | 7.0827 | 6.9308 | 7.3539 | 22.777 | 3.410 |
| **50%** | 15.028 | 14.838 | 15.248 | 28.460 | 6.310 |
| **75%** | 25.382 | 25.142 | 25.536 | 33.922 | 11.677 |
| **90%** | 34.570 | 34.286 | 34.665 | 38.575 | 20.319 |
| **95%** | 39.200 | 38.894 | 39.266 | 41.234 | 28.306 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min.** | NA | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev.** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Carpets – All Tests

| $CO_2$ Yield (kg/kg) | | | | | | CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Gamma | Weibull | Weibull | Lognorm | **Distrib.** | Weibull | Lognorm | Weibull | Triangle | Gamma |
| **No. Tests** | 47 | 47 | 47 | 47 | 27 | **No. Tests** | 44 | 44 | 44 | 44 | 27 |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 | **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf | **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.9004 | 1.3817 | 2.0638 | 2.3156 | 1.6485 | **Mean** | 0.0683 | 0.0327 | 0.0789 | 0.1212 | 0.0991 |
| **Mode** | 1.137 | 0.5964 | 1.4021 | 1.4093 | 1.3226 | **Mode** | 0.0574 | 0.0234 | 0.0765 | 0.0629 | 0.096 |
| **Std Dev.** | 1.2223 | 1.0417 | 1.2323 | 1.4761 | 0.6556 | **Std Dev.** | 0.0337 | 0.0163 | 0.0295 | 0.0675 | 0.0175 |
| **Alpha (α)** | 1.5911 | 1.7595 | 1.7263 | 1.6067 | NA | **Alpha (α)** | 2.1374 | NA | 2.9059 | NA | 32.08 |
| **Beta (β)** | 2.1185 | 0.7853 | 2.3153 | 2.5837 | NA | **Beta (β)** | 0.07717 | NA | 0.088501 | NA | 0.00309 |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 0.3276 | 0.2069 | 0.4144 | 0.4068 | 0.8156 | **5%** | 0.0192 | 0.0134 | 0.0318 | 0.0202 | 0.0722 |
| **10%** | 0.515 | 0.3231 | 0.6287 | 0.6367 | 0.9374 | **10%** | 0.0269 | 0.016 | 0.0408 | 0.0286 | 0.0774 |
| **25%** | 0.9682 | 0.6182 | 1.125 | 1.1898 | 1.183 | **25%** | 0.0431 | 0.0213 | 0.0576 | 0.0452 | 0.0868 |
| **50%** | 1.6826 | 1.1306 | 1.8724 | 2.0567 | 1.5318 | **50%** | 0.065 | 0.0292 | 0.078 | 0.064 | 0.0981 |
| **75%** | 2.6013 | 1.8756 | 2.7976 | 3.1662 | 1.9836 | **75%** | 0.0899 | 0.0402 | 0.099 | 0.0809 | 0.1103 |
| **90%** | 3.5784 | 2.7703 | 3.7535 | 4.342 | 2.5032 | **90%** | 0.114 | 0.0536 | 0.1179 | 0.0957 | 0.1221 |
| **95%** | 4.222 | 3.4149 | 4.3716 | 5.1147 | 2.8771 | **95%** | 0.1289 | 0.0636 | 0.1291 | 0.1032 | 0.1295 |

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Weibull | Weibull | Weibull | Gamma | **Distrib.** | NA | | | | |
| **No. Tests** | 47 | 47 | 47 | 47 | 27 | **No. Tests** | NA | | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 | **Min.** | NA | | | | |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf | **Max.** | | | | | |
| **Mean** | 15.8443 | 17.3332 | 15.3747 | 18.6046 | 10.1619 | **Mean** | | | | | |
| **Mode** | 3.0223 | 1.3879 | 3.5615 | 4.6094 | 4.9145 | **Mode** | | | | | |
| **Std Dev.** | 13.7004 | 16.212 | 12.9299 | 15.4766 | 7.3023 | **Std Dev.** | | | | | |
| **Alpha (α)** | 1.1598 | 1.0698 | 1.1939 | 1.2.76 | 1.9366 | **Alpha (α)** | | | | | |
| **Beta (β)** | 16.689 | 17.793 | 16.323 | 19.81 | 5.2473 | **Beta (β)** | | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 1.289 | 1.1079 | 1.3563 | 1.6932 | 1.7328 | **5%** | NA | | | | |
| **10%** | 2.3977 | 2.1713 | 2.4786 | 3.0731 | 2.6198 | **10%** | | | | | |
| **25%** | 5.7006 | 5.5525 | 5.749 | 7.0602 | 4.8007 | **25%** | | | | | |
| **50%** | 12.1674 | 12.632 | 12.0082 | 14.6244 | 8.4764 | **50%** | | | | | |
| **75%** | 22.1179 | 24.1465 | 21.4594 | 25.9632 | 13.7103 | **75%** | | | | | |
| **90%** | 34.256 | 38.7999 | 32.8237 | 39.5218 | 19.9142 | **90%** | | | | | |
| **95%** | 42.9808 | 49.6202 | 40.9179 | 49.1447 | 24.3512 | **95%** | | | | | |

# Foam Fabric Combinations – Without Barriers

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | NA | | | |
| **No. Tests** | 24 | NA | | | |
| **Parameter** | | | | | |
| **Min.** | 0 | NA | | | |
| **Max.** | +Inf | | | | |
| **Mean** | 1.652 | | | | |
| **Mode** | 1.4141 | | | | |
| **Std Dev** | 0.6268 | | | | |
| **Alpha (α)** | 6.9462 | | | | |
| **Beta (β)** | 0.23782 | | | | |
| **Percentile** | | | | | |
| **5%** | 0.7726 | NA | | | |
| **10%** | 0.9166 | | | | |
| **25%** | 1.1977 | | | | |
| **50%** | 1.5734 | | | | |
| **75%** | 2.0209 | | | | |
| **90%** | 2.4888 | | | | |
| **95%** | 2.7995 | | | | |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | NA | | | |
| **No. Tests** | 24 | NA | | | |
| **Parameter** | | | | | |
| **Min.** | 0 | NA | | | |
| **Max.** | +Inf | | | | |
| **Mean** | 0.0402 | | | | |
| **Mode** | 0.0161 | | | | |
| **Std Dev** | 0.0311 | | | | |
| **Alpha (α)** | 1.6718 | | | | |
| **Beta (β)** | 0.024029 | | | | |
| **Percentile** | | | | | |
| **5%** | 0.00559 | NA | | | |
| **10%** | 0.00889 | | | | |
| **25%** | 0.0174 | | | | |
| **50%** | 0.0325 | | | | |
| **75%** | 0.0547 | | | | |
| **90%** | 0.0815 | | | | |
| **95%** | 0.101 | | | | |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | NA | | | |
| **No. Tests** | 24 | NA | | | |
| **Parameter** | | | | | |
| **Min.** | 0 | NA | | | |
| **Max.** | +Inf | | | | |
| **Mean** | 20.3222 | | | | |
| **Mode** | 20.7891 | | | | |
| **Std Dev** | 5.8828 | | | | |
| **Alpha (α)** | 3.8637 | | | | |
| **Beta (β)** | 22.465 | | | | |
| **Percentile** | | | | | |
| **5%** | 10.4145 | NA | | | |
| **10%** | 12.5473 | | | | |
| **25%** | 16.2726 | | | | |
| **50%** | 20.4317 | | | | |
| **75%** | 24.4465 | | | | |
| **90%** | 27.8773 | | | | |
| **95%** | 29.8422 | | | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | NA | | | |
| **No. Tests** | 24 | NA | | | |
| **Parameter** | | | | | |
| **Min.** | 0 | NA | | | |
| **Max.** | +Inf | | | | |
| **Mean** | 0.0114 | | | | |
| **Mode** | 6.55E-08 | | | | |
| **Std Dev** | 0.637 | | | | |
| **Alpha (α)** | NA | | | | |
| **Beta (β)** | NA | | | | |
| **Percentile** | | | | | |
| **5%** | 1.92E-06 | NA | | | |
| **10%** | 5.39E-06 | | | | |
| **25%** | 3.02E-05 | | | | |
| **50%** | 0.000204 | | | | |
| **75%** | 0.00138 | | | | |
| **90%** | 0.00774 | | | | |
| **95%** | 0.0217 | | | | |

# Foam Fabric Combinations – With Barriers (Aramid (Kevlar) Interliner, Knitted Glass Charring Fibre, or Woven Glass Fibre)

| $CO_2$ Yield (kg/kg) | | | | | | CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | NA | | | | **Distrib.** | Gamma | NA | | | |
| **No. Tests** | 104 | NA | | | | **No. Tests** | 104 | NA | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | NA | | | | **Min.** | 0 | NA | | | |
| **Max.** | +Inf | | | | | **Max.** | +Inf | | | | |
| **Mean** | 1.7038 | | | | | **Mean** | 0.0364 | | | | |
| **Mode** | 1.0797 | | | | | **Mode** | 0.00416 | | | | |
| **Std Dev** | 1.0311 | | | | | **Std Dev** | 0.0342 | | | | |
| **Alpha (α)** | 2.7302 | | | | | **Alpha (α)** | 1.1291 | | | | |
| **Beta (β)** | 0.62405 | | | | | **Beta (β)** | 0.032201 | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 0.4259 | NA | | | | **5%** | 0.00248 | NA | | | |
| **10%** | 0.5862 | | | | | **10%** | 0.00473 | | | | |
| **25%** | 0.9457 | | | | | **25%** | 0.0118 | | | | |
| **50%** | 1.5009 | | | | | **50%** | 0.0264 | | | | |
| **75%** | 2.2428 | | | | | **75%** | 0.0503 | | | | |
| **90%** | 3.0859 | | | | | **90%** | 0.0812 | | | | |
| **95%** | 3.6748 | | | | | **95%** | 0.1044 | | | | |

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Triangle | NA | | | | **Distrib.** | Expon | NA | | | |
| **No. Tests** | 104 | NA | | | | **No. Tests** | 104 | NA | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | NA | | | | **Min.** | 0 | NA | | | |
| **Max.** | 39.7404 | | | | | **Max.** | +Inf | | | | |
| **Mean** | 21.4561 | | | | | **Mean** | 0.0313 | | | | |
| **Mode** | 24.628 | | | | | **Mode** | 0 | | | | |
| **Std Dev** | 8.1891 | | | | | **Std Dev** | 0.0313 | | | | |
| **Alpha (α)** | NA | | | | | **Alpha (α)** | NA | | | | |
| **Beta (β)** | NA | | | | | **Beta (β)** | 0.031292 | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 6.9955 | NA | | | | **5%** | 0.00161 | NA | | | |
| **10%** | 9.8931 | | | | | **10%** | 0.0033 | | | | |
| **25%** | 15.6423 | | | | | **25%** | 0.009 | | | | |
| **50%** | 22.1216 | | | | | **50%** | 0.0217 | | | | |
| **75%** | 27.4871 | | | | | **75%** | 0.0434 | | | | |
| **90%** | 31.9908 | | | | | **90%** | 0.0721 | | | | |
| **95%** | 34.2606 | | | | | **95%** | 0.0937 | | | | |

# Foam Fabric Combinations – Cordura Nylon Fabric (100% or 63%)

| $CO_2$ Yield (kg/kg) | | | | | | CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | NA | | | | **Distrib.** | Gamma | NA | | | |
| **No. Tests** | 15 | NA | | | | **No. Tests** | 15 | NA | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | NA | | | | **Min.** | 0 | NA | | | |
| **Max.** | +Inf | | | | | **Max.** | +Inf | | | | |
| **Mean** | 1.9178 | | | | | **Mean** | 0.0316 | | | | |
| **Mode** | 2.0036 | | | | | **Mode** | 0.0161 | | | | |
| **Std Dev** | 0.3958 | | | | | **Std Dev** | 0.0222 | | | | |
| **Alpha (α)** | 5.6027 | | | | | **Alpha (α)** | 2.0325 | | | | |
| **Beta (β)** | 2.0752 | | | | | **Beta (β)** | 0.015564 | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 1.2213 | NA | | | | **5%** | 0.00574 | NA | | | |
| **10%** | 1.3887 | | | | | **10%** | 0.00854 | | | | |
| **25%** | 1.6614 | | | | | **25%** | 0.0153 | | | | |
| **50%** | 1.9438 | | | | | **50%** | 0.0266 | | | | |
| **75%** | 2.1997 | | | | | **75%** | 0.0425 | | | | |
| **90%** | 2.4083 | | | | | **90%** | 0.0613 | | | | |
| **95%** | 2.5241 | | | | | **95%** | 0.0747 | | | | |

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | NA | | | | **Distrib.** | Triangle | NA | | | |
| **No. Tests** | 15 | NA | | | | **No. Tests** | 15 | NA | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | | | | | **Min.** | 0 | NA | | | |
| **Max.** | +Inf | | | | | **Max.** | 0.000284 | | | | |
| **Mean** | 23.0327 | | | | | **Mean** | 9.63E-05 | | | | |
| **Mode** | 22.4892 | | | | | **Mode** | 4.63E-06 | | | | |
| **Std Dev** | 3.5381 | | | | | **Std Dev** | 6.64E-05 | | | | |
| **Alpha (α)** | 42.378 | | | | | **Alpha (α)** | NA | | | | |
| **Beta (β)** | 0.5435 | | | | | **Beta (β)** | NA | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 17.5379 | NA | | | | **5%** | 9.46E-06 | NA | | | |
| **10%** | 18.6306 | | | | | **10%** | 1.68E-05 | | | | |
| **25%** | 20.5579 | | | | | **25%** | 4.01E-05 | | | | |
| **50%** | 22.8518 | | | | | **50%** | 8.49E-05 | | | | |
| **75%** | 25.3103 | | | | | **75%** | 0.000143 | | | | |
| **90%** | 27.6674 | | | | | **90%** | 0.000195 | | | | |
| **95%** | 29.1446 | | | | | **95%** | 0.000221 | | | | |

# Foam Fabric Combinations – Cotton Fabric (100%, 75%, 62% or 60%)

| $CO_2$ Yield (kg/kg) | | | | | | CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Stages | All | G | TS | T | S | Stages | All | G | TS | T | S |
| Distrib. | Weibull | NA | | | | Distrib. | Gamma | NA | | | |
| No. Tests | 49 | NA | | | | No. Tests | 49 | NA | | | |
| Parameter | | | | | | Parameter | | | | | |
| Min. | 0 | NA | | | | Min. | 0 | NA | | | |
| Max. | +Inf | | | | | Max. | +Inf | | | | |
| Mean | 1.6069 | | | | | Mean | 0.0201 | | | | |
| Mode | 1.5801 | | | | | Mode | 0.00581 | | | | |
| Std Dev | 0.5734 | | | | | Std Dev | 0.0169 | | | | |
| Alpha (α) | 3.0622 | | | | | Alpha (α) | 1.4081 | | | | |
| Beta (β) | 1.7979 | | | | | Beta (β) | 0.014246 | | | | |
| Percentile | | | | | | Percentile | | | | | |
| 5% | 0.6816 | NA | | | | 5% | 0.00211 | NA | | | |
| 10% | 0.8622 | | | | | 10% | 0.00361 | | | | |
| 25% | 1.1969 | | | | | 25% | 0.00775 | | | | |
| 50% | 1.595 | | | | | 50% | 0.0156 | | | | |
| 75% | 2.0002 | | | | | 75% | 0.0276 | | | | |
| 90% | 2.3607 | | | | | 90% | 0.0425 | | | | |
| 95% | 2.5726 | | | | | 95% | 0.0534 | | | | |

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Stages | All | G | TS | T | S | Stages | All | G | TS | T | S |
| Distrib. | Weibull | NA | | | | Distrib. | Expon | NA | | | |
| No. Tests | 49 | NA | | | | No. Tests | 49 | NA | | | |
| Parameter | | | | | | Parameter | | | | | |
| Min. | 0 | NA | | | | Min. | 0 | NA | | | |
| Max. | +Inf | | | | | Max. | +Inf | | | | |
| Mean | 18.3379 | | | | | Mean | 0.00917 | | | | |
| Mode | 18.0837 | | | | | Mode | 0 | | | | |
| Std Dev | 6.4727 | | | | | Std Dev | 0.00917 | | | | |
| Alpha (α) | 3.0995 | | | | | Alpha (α) | NA | | | | |
| Beta (β) | 20.505 | | | | | Beta (β) | 0.00917 | | | | |
| Percentile | | | | | | Percentile | | | | | |
| 5% | 7.8649 | NA | | | | 5% | 0.000471 | NA | | | |
| 10% | 9.9209 | | | | | 10% | 0.000966 | | | | |
| 25% | 13.7181 | | | | | 25% | 0.00264 | | | | |
| 50% | 18.2185 | | | | | 50% | 0.00636 | | | | |
| 75% | 22.7843 | | | | | 75% | 0.0127 | | | | |
| 90% | 26.8368 | | | | | 90% | 0.0211 | | | | |
| 95% | 29.2148 | | | | | 95% | 0.0275 | | | | |

# Foam Fabric Combinations – Modacrylic Fabric (75%)

| $CO_2$ Yield (kg/kg) | | | | | | CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | NA | | | | **Distrib.** | Gamma | NA | | | |
| **No. Tests** | 15 | NA | | | | **No. Tests** | 15 | NA | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | NA | | | | **Min.** | 0 | NA | | | |
| **Max.** | +Inf | | | | | **Max.** | +Inf | | | | |
| **Mean** | 1.1293 | | | | | **Mean** | 0.073 | | | | |
| **Mode** | 0.4868 | | | | | **Mode** | 0.0367 | | | | |
| **Std Dev** | 0.8518 | | | | | **Std Dev** | 0.0514 | | | | |
| **Alpha (α)** | 1.7577 | | | | | **Alpha (α)** | 2.0117 | | | | |
| **Beta (β)** | 0.64249 | | | | | **Beta (β)** | 0.036269 | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 0.1688 | NA | | | | **5%** | 0.0131 | NA | | | |
| **10%** | 0.2638 | | | | | **10%** | 0.0195 | | | | |
| **25%** | 0.505 | | | | | **25%** | 0.0352 | | | | |
| **50%** | 0.9238 | | | | | **50%** | 0.0613 | | | | |
| **75%** | 1.533 | | | | | **75%** | 0.0982 | | | | |
| **90%** | 2.2647 | | | | | **90%** | 0.1417 | | | | |
| **95%** | 2.7918 | | | | | **95%** | 0.1727 | | | | |

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Uniform | NA | | | | **Distrib.** | Expon | NA | | | |
| **No. Tests** | 15 | NA | | | | **No. Tests** | 15 | NA | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | NA | | | | **Min.** | 0 | NA | | | |
| **Max.** | 27.9448 | | | | | **Max.** | +Inf | | | | |
| **Mean** | 13.9724 | | | | | **Mean** | 0.0544 | | | | |
| **Mode** | 0 | | | | | **Mode** | 0 | | | | |
| **Std Dev** | 8.067 | | | | | **Std Dev** | 0.0544 | | | | |
| **Alpha (α)** | NA | | | | | **Alpha (α)** | NA | | | | |
| **Beta (β)** | NA | | | | | **Beta (β)** | 0.054417 | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 1.3972 | NA | | | | **5%** | 0.00279 | NA | | | |
| **10%** | 2.7945 | | | | | **10%** | 0.00573 | | | | |
| **25%** | 6.9862 | | | | | **25%** | 0.0157 | | | | |
| **50%** | 13.9724 | | | | | **50%** | 0.0377 | | | | |
| **75%** | 20.9586 | | | | | **75%** | 0.0754 | | | | |
| **90%** | 25.1503 | | | | | **90%** | 0.1253 | | | | |
| **95%** | 26.5475 | | | | | **95%** | 0.163 | | | | |

# Foam Fabric Combinations – Nylon Fabric (100%)

| $CO_2$ Yield (kg/kg) | | | | | | CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | NA | | | | **Distrib.** | Gamma | NA | | | |
| **No. Tests** | 9 | NA | | | | **No. Tests** | 9 | NA | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | NA | | | | **Min.** | 0 | NA | | | |
| **Max.** | +Inf | | | | | **Max.** | +Inf | | | | |
| **Mean** | 2.045 | | | | | **Mean** | 0.0206 | | | | |
| **Mode** | 2.1201 | | | | | **Mode** | 0.0136 | | | | |
| **Std Dev** | 0.5122 | | | | | **Std Dev** | 0.012 | | | | |
| **Alpha (α)** | 4.5328 | | | | | **Alpha (α)** | 2.9459 | | | | |
| **Beta (β)** | 2.24 | | | | | **Beta (β)** | 0.006979 | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 1.1632 | NA | | | | **5%** | 0.00551 | NA | | | |
| **10%** | 1.3634 | | | | | **10%** | 0.00746 | | | | |
| **25%** | 1.7016 | | | | | **25%** | 0.0118 | | | | |
| **50%** | 2.066 | | | | | **50%** | 0.0183 | | | | |
| **75%** | 2.4073 | | | | | **75%** | 0.0269 | | | | |
| **90%** | 2.6925 | | | | | **90%** | 0.0366 | | | | |
| **95%** | 2.8534 | | | | | **95%** | 0.0434 | | | | |

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | NA | | | | **Distrib.** | Triangle | NA | | | |
| **No. Tests** | 9 | NA | | | | **No. Tests** | 9 | NA | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | NA | | | | **Min.** | 0 | NA | | | |
| **Max.** | +Inf | | | | | **Max.** | 0.0771 | | | | |
| **Mean** | 24.6888 | | | | | **Mean** | 0.0409 | | | | |
| **Mode** | 25.6919 | | | | | **Mode** | 0.0455 | | | | |
| **Std Dev** | 3.0377 | | | | | **Std Dev** | 0.0158 | | | | |
| **Alpha (α)** | 9.7653 | | | | | **Alpha (α)** | NA | | | | |
| **Beta (β)** | 25.978 | | | | | **Beta (β)** | NA | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 19.1649 | NA | | | | **5%** | 0.0132 | NA | | | |
| **10%** | 20.6309 | | | | | **10%** | 0.0187 | | | | |
| **25%** | 22.8661 | | | | | **25%** | 0.0296 | | | | |
| **50%** | 25.0208 | | | | | **50%** | 0.0419 | | | | |
| **75%** | 26.8613 | | | | | **75%** | 0.0524 | | | | |
| **90%** | 28.2939 | | | | | **90%** | 0.0615 | | | | |
| **95%** | 29.0667 | | | | | **95%** | 0.0661 | | | | |

# Foam Fabric Combinations – Polyester Fabric (100%)

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Weibull | NA | | | |
| No. Tests | 9 | NA | | | |
| Parameter | | | | | |
| Min. | 0 | NA | | | |
| Max. | +Inf | | | | |
| Mean | 1.8852 | | | | |
| Mode | 1.9515 | | | | |
| Std Dev | 0.4825 | | | | |
| Alpha (α) | 4.4266 | | | | |
| Beta (β) | 2.0677 | | | | |
| Percentile | | | | | |
| 5% | 1.057 | NA | | | |
| 10% | 1.2437 | | | | |
| 25% | 1.5605 | | | | |
| 50% | 1.9034 | | | | |
| 75% | 2.2261 | | | | |
| 90% | 2.4964 | | | | |
| 95% | 2.6494 | | | | |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Gamma | NA | | | |
| No. Tests | 9 | NA | | | |
| Parameter | | | | | |
| Min. | 0 | NA | | | |
| Max. | +Inf | | | | |
| Mean | 0.0328 | | | | |
| Mode | 0.0162 | | | | |
| Std Dev | 0.0234 | | | | |
| Alpha (α) | 1.9756 | | | | |
| Beta (β) | 0.016625 | | | | |
| Percentile | | | | | |
| 5% | 0.00575 | NA | | | |
| 10% | 0.00863 | | | | |
| 25% | 0.0157 | | | | |
| 50% | 0.0275 | | | | |
| 75% | 0.0443 | | | | |
| 90% | 0.0641 | | | | |
| 95% | 0.0782 | | | | |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Weibull | NA | | | |
| No. Tests | 9 | NA | | | |
| Parameter | | | | | |
| Min. | 0 | NA | | | |
| Max. | +Inf | | | | |
| Mean | 20.34 | | | | |
| Mode | 21.2651 | | | | |
| Std Dev | 3.3158 | | | | |
| Alpha (α) | 7.2316 | | | | |
| Beta (β) | 21.707 | | | | |
| Percentile | | | | | |
| 5% | 14.3956 | NA | | | |
| 10% | 15.9023 | | | | |
| 25% | 18.2719 | | | | |
| 50% | 20.6346 | | | | |
| 75% | 22.7103 | | | | |
| 90% | 24.361 | | | | |
| 95% | 25.2638 | | | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Triangle | NA | | | |
| No. Tests | 9 | NA | | | |
| Parameter | | | | | |
| Min. | 0 | NA | | | |
| Max. | 0.0907 | | | | |
| Mean | 0.0302 | | | | |
| Mode | 6.90E-05 | | | | |
| Std Dev | 0.0214 | | | | |
| Alpha (α) | NA | | | | |
| Beta (β) | NA | | | | |
| Percentile | | | | | |
| 5% | 0.00233 | NA | | | |
| 10% | 0.00469 | | | | |
| 25% | 0.0122 | | | | |
| 50% | 0.0266 | | | | |
| 75% | 0.0454 | | | | |
| 90% | 0.062 | | | | |
| 95% | 0.0704 | | | | |

# Foam Fabric Combinations – Polypropylene (Heavy or Light) (100%)

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | NA | | | |
| **No. Tests** | 25 | NA | | | |
| **Parameter** | | | | | |
| **Min.** | 0 | NA | | | |
| **Max.** | +Inf | | | | |
| **Mean** | 1.8585 | | | | |
| **Mode** | 0.9028 | | | | |
| **Std Dev** | 1.3327 | | | | |
| **Alpha (α)** | 1.9446 | | | | |
| **Beta (β)** | 0.95571 | | | | |
| **Percentile** | | | | | |
| **5%** | 0.3186 | NA | | | |
| **10%** | 0.4811 | | | | |
| **25%** | 0.88 | | | | |
| **50%** | 1.5515 | | | | |
| **75%** | 2.5068 | | | | |
| **90%** | 3.6385 | | | | |
| **95%** | 4.4477 | | | | |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | NA | | | |
| **No. Tests** | 25 | NA | | | |
| **Parameter** | | | | | |
| **Min.** | 0 | NA | | | |
| **Max.** | +Inf | | | | |
| **Mean** | 0.0455 | | | | |
| **Mode** | 0.00187 | | | | |
| **Std Dev** | 0.0445 | | | | |
| **Alpha (α)** | 1.043 | | | | |
| **Beta (β)** | 0.04362 | | | | |
| **Percentile** | | | | | |
| **5%** | 0.00259 | NA | | | |
| **10%** | 0.00517 | | | | |
| **25%** | 0.0136 | | | | |
| **50%** | 0.0321 | | | | |
| **75%** | 0.063 | | | | |
| **90%** | 0.1037 | | | | |
| **95%** | 0.1343 | | | | |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Triangle | NA | | | |
| **No. Tests** | 25 | NA | | | |
| **Parameter** | | | | | |
| **Min.** | 0 | NA | | | |
| **Max.** | 39.8645 | | | | |
| **Mean** | 23.3146 | | | | |
| **Mode** | 30.0794 | | | | |
| **Std Dev** | 8.4815 | | | | |
| **Alpha (α)** | NA | | | | |
| **Beta (β)** | NA | | | | |
| **Percentile** | | | | | |
| **5%** | 7.7431 | NA | | | |
| **10%** | 10.9503 | | | | |
| **25%** | 17.314 | | | | |
| **50%** | 24.4857 | | | | |
| **75%** | 29.9888 | | | | |
| **90%** | 33.6189 | | | | |
| **95%** | 35.4482 | | | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | NA | | | |
| **No. Tests** | 25 | NA | | | |
| **Parameter** | | | | | |
| **Min.** | 0 | NA | | | |
| **Max.** | +Inf | | | | |
| **Mean** | 0.0506 | | | | |
| **Mode** | 0.00159 | | | | |
| **Std Dev** | 0.0498 | | | | |
| **Alpha (α)** | 1.0324 | | | | |
| **Beta (β)** | 0.049042 | | | | |
| **Percentile** | | | | | |
| **5%** | 0.00281 | NA | | | |
| **10%** | 0.00565 | | | | |
| **25%** | 0.015 | | | | |
| **50%** | 0.0355 | | | | |
| **75%** | 0.0702 | | | | |
| **90%** | 0.1157 | | | | |
| **95%** | 0.15 | | | | |

# Foam Fabric Combinations – Vinyl Fabric (100%)

| $CO_2$ Yield (kg/kg) | | | | | | CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | NA | | | | **Distrib.** | Gamma | NA | | | |
| **No. Tests** | 6 | NA | | | | **No. Tests** | 6 | NA | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | NA | | | | **Min.** | 0 | NA | | | |
| **Max.** | +Inf | | | | | **Max.** | +Inf | | | | |
| **Mean** | 1.4523 | | | | | **Mean** | 0.0519 | | | | |
| **Mode** | 1.4844 | | | | | **Mode** | 0.0332 | | | | |
| **Std Dev** | 0.4234 | | | | | **Std Dev** | 0.0312 | | | | |
| **Alpha (α)** | 3.8338 | | | | | **Alpha (α)** | 2.7664 | | | | |
| **Beta (β)** | 1.6062 | | | | | **Beta (β)** | 0.018769 | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 0.7402 | NA | | | | **5%** | 0.0131 | NA | | | |
| **10%** | 0.893 | | | | | **10%** | 0.018 | | | | |
| **25%** | 1.1605 | | | | | **25%** | 0.029 | | | | |
| **50%** | 1.4597 | | | | | **50%** | 0.0458 | | | | |
| **75%** | 1.749 | | | | | **75%** | 0.0683 | | | | |
| **90%** | 1.9965 | | | | | **90%** | 0.0938 | | | | |
| **95%** | 2.1384 | | | | | **95%** | 0.1116 | | | | |

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Triangle | NA | | | | **Distrib.** | Gamma | NA | | | |
| **No. Tests** | 6 | NA | | | | **No. Tests** | 6 | NA | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | NA | | | | **Min.** | 0 | NA | | | |
| **Max.** | 32.1556 | | | | | **Max.** | +Inf | | | | |
| **Mean** | 20.2537 | | | | | **Mean** | 0.000105 | | | | |
| **Mode** | 28.6055 | | | | | **Mode** | 2.30E-05 | | | | |
| **Std Dev** | 7.1973 | | | | | **Std Dev** | 9.32E-05 | | | | |
| **Alpha (α)** | NA | | | | | **Alpha (α)** | 1.2789 | | | | |
| **Beta (β)** | NA | | | | | **Beta (β)** | 0.0000824 | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 6.7817 | NA | | | | **5%** | 9.29E-06 | NA | | | |
| **10%** | 9.5908 | | | | | **10%** | 1.66E-05 | | | | |
| **25%** | 15.1643 | | | | | **25%** | 3.78E-05 | | | | |
| **50%** | 21.4456 | | | | | **50%** | 7.95E-05 | | | | |
| **75%** | 26.2654 | | | | | **75%** | 0.000145 | | | | |
| **90%** | 28.7769 | | | | | **90%** | 0.000228 | | | | |
| **95%** | 29.7665 | | | | | **95%** | 0.00029 | | | | |

# Foam Fabric Combinations – All Tests

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Gamma | NA | | | |
| No. Tests | 128 | NA | | | |
| Parameter | | | | | |
| Min. | 0 | NA | | | |
| Max. | +Inf | | | | |
| Mean | 1.702 | | | | |
| Mode | 1.148 | | | | |
| Std Dev. | 0.971 | | | | |
| Alpha (α) | 3.0722 | | | | |
| Beta (β) | 0.55399 | | | | |
| Percentile | | | | | |
| 5% | 0.4736 | NA | | | |
| 10% | 0.6351 | | | | |
| 25% | 0.9886 | | | | |
| 50% | 1.5213 | | | | |
| 75% | 2.22 | | | | |
| 90% | 3.0039 | | | | |
| 95% | 3.5475 | | | | |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Gamma | NA | | | |
| No. Tests | 128 | NA | | | |
| Parameter | | | | | |
| Min. | 0 | NA | | | |
| Max. | +Inf | | | | |
| Mean | 0.0372 | | | | |
| Mode | 0.00619 | | | | |
| Std Dev | 0.034 | | | | |
| Alpha (α) | 1.1993 | | | | |
| Beta (β) | 0.03106 | | | | |
| Percentile | | | | | |
| 5% | 0.00289 | NA | | | |
| 10% | 0.00533 | | | | |
| 25% | 0.0127 | | | | |
| 50% | 0.0276 | | | | |
| 75% | 0.0515 | | | | |
| 90% | 0.082 | | | | |
| 95% | 0.1047 | | | | |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Triangle | NA | | | |
| No. Tests | 128 | NA | | | |
| Parameter | | | | | |
| Min. | 0 | NA | | | |
| Max. | 39.7394 | | | | |
| Mean | 20.924 | | | | |
| Mode | 23.0327 | | | | |
| Std Dev | 8.146 | | | | |
| Alpha (α) | NA | | | | |
| Beta (β) | NA | | | | |
| Percentile | | | | | |
| 5% | 6.765 | NA | | | |
| 10% | 9.5672 | | | | |
| 25% | 15.127 | | | | |
| 50% | 21.3928 | | | | |
| 75% | 26.8562 | | | | |
| 90% | 31.5913 | | | | |
| 95% | 33.9779 | | | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Expon | NA | | | |
| No. Tests | 128 | NA | | | |
| Parameter | | | | | |
| Min. | 0 | NA | | | |
| Max. | +Inf | | | | |
| Mean | 0.0283 | | | | |
| Mode | 0 | | | | |
| Std Dev | 0.0283 | | | | |
| Alpha (α) | NA | | | | |
| Beta (β) | 0.02835 | | | | |
| Percentile | | | | | |
| 5% | 0.00145 | NA | | | |
| 10% | 0.00299 | | | | |
| 25% | 0.00816 | | | | |
| 50% | 0.0197 | | | | |
| 75% | 0.0393 | | | | |
| 90% | 0.0653 | | | | |
| 95% | 0.0849 | | | | |

# Foam and Fabric Combinations – Standard Foams

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Weibull | Triangle | Lognorm | NA | |
| No. Tests | 9 | 9 | 9 | NA | |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | NA | |
| Max. | +Inf | 3.1066 | +Inf | | |
| Mean | 2.2821 | 1.7251 | 2.8161 | | |
| Mode | 2.2385 | 2.0688 | 2.6596 | | |
| Std Dev | 0.8216 | 0.6457 | 0.555 | | |
| Alpha (α) | 3.032 | NA | NA | | |
| Beta (β) | 2.5544 | NA | NA | | |
| Percentile | | | | | |
| 5% | 0.9591 | 0.5669 | 2.0041 | NA | |
| 10% | 1.216 | 0.8017 | 2.1514 | | |
| 25% | 1.6937 | 1.2676 | 2.4221 | | |
| 50% | 2.2635 | 1.7926 | 2.7629 | | |
| 75% | 2.8449 | 2.2088 | 3.1517 | | |
| 90% | 3.3631 | 2.5388 | 3.5482 | | |
| 95% | 3.6681 | 2.7051 | 3.809 | | |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Weibull | Weibull | Gamma | NA | |
| No. Tests | 9 | 9 | 9 | NA | |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | NA | |
| Max. | +Inf | +Inf | +Inf | | |
| Mean | 0.018 | 0.0185 | 0.0174 | | |
| Mode | 0.00963 | 0.0141 | 0.00703 | | |
| Std Dev | 0.0122 | 0.0101 | 0.0134 | | |
| Alpha (α) | 1.5029 | 1.9021 | 1.6789 | | |
| Beta (β) | 0.0199 | 0.0209 | 0.0104 | | |
| Percentile | | | | | |
| 5% | 0.00276 | 0.00438 | 0.00243 | NA | |
| 10% | 0.00446 | 0.00639 | 0.00386 | | |
| 25% | 0.00871 | 0.0108 | 0.00756 | | |
| 50% | 0.0156 | 0.0172 | 0.0141 | | |
| 75% | 0.0248 | 0.0248 | 0.0237 | | |
| 90% | 0.0347 | 0.0323 | 0.0353 | | |
| 95% | 0.0414 | 0.0371 | 0.0436 | | |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Triangle | Triangle | Lognorm | NA | |
| No. Tests | 9 | 9 | 9 | NA | |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | NA | |
| Max. | 51.842 | 42.270 | +Inf | | |
| Mean | 25.822 | 21.345 | 28.838 | | |
| Mode | 25.625 | 21.764 | 26.637 | | |
| Std Dev | 10.582 | 8.630 | 6.7232 | | |
| Alpha (α) | NA | NA | NA | | |
| Beta (β) | NA | NA | NA | | |
| Percentile | | | | | |
| 5% | 8.15 | 6.7822 | 19.237 | NA | |
| 10% | 11.526 | 9.5915 | 20.914 | | |
| 25% | 18.224 | 15.166 | 24.049 | | |
| 50% | 25.774 | 21.447 | 28.085 | | |
| 75% | 33.409 | 27.549 | 32.799 | | |
| 90% | 40.184 | 32.960 | 37.715 | | |
| 95% | 43.598 | 35.687 | 41.003 | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | NA | | | | |
| No. Tests | NA | | | | |
| Parameter | | | | | |
| Min. | NA | | | | |
| Max. | | | | | |
| Mean | | | | | |
| Mode | | | | | |
| Std Dev | | | | | |
| Alpha (α) | | | | | |
| Beta (β) | | | | | |
| Percentile | | | | | |
| 5% | NA | | | | |
| 10% | | | | | |
| 25% | | | | | |
| 50% | | | | | |
| 75% | | | | | |
| 90% | | | | | |
| 95% | | | | | |

# Foam and Fabric Combinations – High Resilience Foams

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Weibull | Lognorm | NA | |
| **No. Tests** | 14 | 14 | 14 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 2.0454 | 1.6125 | 2.981 | | |
| **Mode** | 1.7208 | 1.5927 | 2.6987 | | |
| **Std Dev** | 1.0061 | 0.5656 | 0.7806 | | |
| **Alpha (α)** | 2.14 | 3.1214 | NA | | |
| **Beta (β)** | 2.3095 | 1.8025 | NA | | |
| **Percentile** | | | | | |
| **5%** | 0.5765 | 0.696 | 1.888 | NA | |
| **10%** | 0.8069 | 0.8765 | 2.0731 | | |
| **25%** | 1.2903 | 1.2093 | 2.424 | | |
| **50%** | 1.946 | 1.6028 | 2.8838 | | |
| **75%** | 2.6904 | 2.0013 | 3.4309 | | |
| **90%** | 3.4102 | 2.3545 | 4.0114 | | |
| **95%** | 3.8564 | 2.5617 | 4.4049 | | |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Weibull | Expon | NA | |
| **No. Tests** | 14 | 14 | 14 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 0.0169 | 0.0151 | 0.0209 | | |
| **Mode** | 0.00352 | 0.00757 | 0 | | |
| **Std Dev** | 0.0144 | 0.0105 | 0.0209 | | |
| **Alpha (α)** | 1.1748 | 1.4604 | NA | | |
| **Beta (β)** | 0.0178 | 0.0167 | 0.0209 | | |
| **Percentile** | | | | | |
| **5%** | 0.00142 | 0.00218 | 0.00107 | NA | |
| **10%** | 0.00263 | 0.00357 | 0.0022 | | |
| **25%** | 0.00618 | 0.00711 | 0.00601 | | |
| **50%** | 0.0131 | 0.013 | 0.0145 | | |
| **75%** | 0.0236 | 0.0209 | 0.0289 | | |
| **90%** | 0.0363 | 0.0295 | 0.0481 | | |
| **95%** | 0.0454 | 0.0354 | 0.0625 | | |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Weibull | Lognorm | NA | |
| **No. Tests** | 14 | 14 | 14 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 21.31 | 18.5189 | 27.8571 | | |
| **Mode** | 19.0334 | 15.4771 | 25.9537 | | |
| **Std Dev** | 9.6051 | 9.1849 | 6.1231 | | |
| **Alpha (α)** | 2.359 | 2.1203 | NA | | |
| **Beta (β)** | 24.046 | 20.91 | NA | | |
| **Percentile** | | | | | |
| **5%** | 6.8271 | 5.1522 | 19.0337 | NA | |
| **10%** | 9.2631 | 7.2349 | 20.5966 | | |
| **25%** | 14.18 | 11.619 | 23.4997 | | |
| **50%** | 20.5858 | 17.5908 | 27.2076 | | |
| **75%** | 27.6169 | 24.3926 | 31.5006 | | |
| **90%** | 34.244 | 30.9874 | 35.9407 | | |
| **95%** | 38.2852 | 35.0821 | 38.8918 | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min.** | NA | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Foam and Fabric Combinations – No Fabrics (Foams only)

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Weibull | Weibull | NA | |
| **No. Tests** | 9 | 9 | 9 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 1.9969 | 1.6182 | 3.2028 | | |
| **Mode** | 1.8028 | 1.5827 | 3.3394 | | |
| **Std Dev** | 0.8834 | 0.5886 | 0.4335 | | |
| **Alpha (α)** | 2.4087 | 2.9972 | 8,825 | | |
| **Beta (β)** | 2.2524 | 1.8122 | 3.385 | | |
| **Percentile** | | | | | |
| **5%** | 0.6563 | 0.6727 | 2.4178 | NA | |
| **10%** | 0.8849 | 0.8553 | 2.6233 | | |
| **25%** | 1.3428 | 1.1958 | 2.9395 | | |
| **50%** | 1.9345 | 1.6036 | 3.2475 | | |
| **75%** | 2.5796 | 2.0209 | 3.5129 | | |
| **90%** | 3.1844 | 2.3936 | 3.7208 | | |
| **95%** | 3.552 | 2.6133 | 3.8334 | | |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Weibull | Triangle | NA | |
| **No. Tests** | 9 | 9 | 9 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | 0.0808 | | |
| **Mean** | 0.0196 | 0.0169 | 0.0284 | | |
| **Mode** | 0.0124 | 0.015 | 0.00446 | | |
| **Std Dev** | 0.0119 | 0.00763 | 0.0186 | | |
| **Alpha (α)** | 2.724 | 2.3485 | NA | | |
| **Beta (β)** | 0.00719 | 0.019035 | NA | | |
| **Percentile** | | | | | |
| **5%** | 0.00488 | 0.00537 | 0.00425 | NA | |
| **10%** | 0.00672 | 0.0073 | 0.00629 | | |
| **25%** | 0.0109 | 0.0112 | 0.0128 | | |
| **50%** | 0.0172 | 0.0163 | 0.0253 | | |
| **75%** | 0.0258 | 0.0219 | 0.0416 | | |
| **90%** | 0.0355 | 0.0272 | 0.056 | | |
| **95%** | 0.0423 | 0.0304 | 0.0633 | | |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Triangle | Triangle | Weibull | NA | |
| **No. Tests** | 9 | 9 | 9 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | 40.535 | 40.3534 | +Inf | | |
| **Mean** | 21.738 | 21.0981 | 29.5093 | | |
| **Mode** | 24.678 | 22.9409 | 30.8553 | | |
| **Std Dev** | 8.3391 | 8.2628 | 4.8799 | | |
| **Alpha (α)** | NA | NA | 7.1211 | | |
| **Beta (β)** | NA | NA | 31.518 | | |
| **Percentile** | | | | | |
| **5%** | 7.0722 | 6.8035 | 20.7689 | NA | |
| **10%** | 10.002 | 9.6216 | 22.9781 | | |
| **25%** | 15.814 | 15.213 | 26.459 | | |
| **50%** | 22.364 | 21.5145 | 29.9368 | | |
| **75%** | 27.858 | 27.0996 | 32.9973 | | |
| **90%** | 32.518 | 31.971 | 35.4343 | | |
| **95%** | 34.866 | 34.4262 | 36.7682 | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min.** | NA | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Foam and Fabric Combinations – Cotton Fabrics

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Weibull | Triangle | Gamma | NA | |
| No. Tests | 8 | 8 | 8 | NA | |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | NA | |
| Max. | +Inf | 2.3404 | +Inf | | |
| Mean | 2.0835 | 1.4203 | 2.5437 | | |
| Mode | 2.1217 | 1.9204 | 2.5157 | | |
| Std Dev | 0.6241 | 0.5094 | 0.267 | | |
| Alpha (α) | 3.7198 | NA | 90.77 | | |
| Beta (β) | 2.308 | NA | 0.0280 | | |
| Percentile | | | | | |
| 5% | 1.0386 | 0.4741 | 2.121 | NA | |
| 10% | 1.2604 | 0.6704 | 2.2081 | | |
| 25% | 1.6511 | 1.06 | 2.3589 | | |
| 50% | 2.0914 | 1.4991 | 2.5344 | | |
| 75% | 2.5198 | 1.836 | 2.7183 | | |
| 90% | 2.8881 | 2.0269 | 2.8913 | | |
| 95% | 3.0998 | 2.1187 | 2.9982 | | |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Gamma | Triangle | Weibull | NA | |
| No. Tests | 8 | 8 | 8 | NA | |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | NA | |
| Max. | +Inf | 0.0202 | +Inf | | |
| Mean | 0.00998 | 0.00689 | 0.0125 | | |
| Mode | 0.0027 | 0.000469 | 0.00159 | | |
| Std Dev | 0.00852 | 0.00471 | 0.0113 | | |
| Alpha (α) | 1.372 | NA | 1.1083 | | |
| Beta (β) | 0.00728 | NA | 0.0130 | | |
| Percentile | | | | | |
| 5% | 0.001 | 0.000742 | 0.00089 | NA | |
| 10% | 0.00173 | 0.00126 | 0.0017 | | |
| 25% | 0.00378 | 0.00291 | 0.00421 | | |
| 50% | 0.00769 | 0.00609 | 0.0093 | | |
| 75% | 0.0137 | 0.0102 | 0.0174 | | |
| 90% | 0.0213 | 0.0139 | 0.0275 | | |
| 95% | 0.0268 | 0.0157 | 0.0349 | | |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Triangle | Triangle | Weibull | NA | |
| No. Tests | 8 | 8 | 8 | NA | |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | NA | |
| Max. | 31.286 | 26.637 | +Inf | | |
| Mean | 19.143 | 15.099 | 24.9672 | | |
| Mode | 26.144 | 18.660 | 25.8632 | | |
| Std Dev | 6.8491 | 5.581 | 2.5163 | | |
| Alpha (α) | NA | NA | 12.054 | | |
| Beta (β) | NA | NA | 26.05 | | |
| Percentile | | | | | |
| 5% | 6.395 | 4.9852 | 20.3605 | NA | |
| 10% | 9.044 | 7.0501 | 21.6134 | | |
| 25% | 14.300 | 11.147 | 23.4916 | | |
| 50% | 20.223 | 15.765 | 25.2695 | | |
| 75% | 24.768 | 19.349 | 26.7652 | | |
| 90% | 27.275 | 22.027 | 27.9159 | | |
| 95% | 28.450 | 23.378 | 28.532 | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | NA | | | | |
| No. Tests | NA | | | | |
| Parameter | | | | | |
| Min. | NA | | | | |
| Max. | | | | | |
| Mean | | | | | |
| Mode | | | | | |
| Std Dev | | | | | |
| Alpha (α) | | | | | |
| Beta (β) | | | | | |
| Percentile | | | | | |
| 5% | NA | | | | |
| 10% | | | | | |
| 25% | | | | | |
| 50% | | | | | |
| 75% | | | | | |
| 90% | | | | | |
| 95% | | | | | |

# Foam and Fabric Combinations – Polypropylene Fabrics

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Weibull | Gamma | NA | |
| **No. Tests** | 6 | 6 | 6 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 2.3705 | 1.8114 | 4.3197 | | |
| **Mode** | 1.6836 | 1.8339 | 3.9937 | | |
| **Std Dev** | 1.2761 | 0.5636 | 1.1867 | | |
| **Alpha (α)** | 3.451 | 3.5664 | 13.251 | | |
| **Beta (β)** | 0.687 | 2.0112 | 0.3260 | | |
| **Percentile** | | | | | |
| **5%** | 0.7259 | 0.8745 | 2.5698 | NA | |
| **10%** | 0.9514 | 1.0701 | 2.8857 | | |
| **25%** | 1.4341 | 1.4182 | 3.4715 | | |
| **50%** | 2.1459 | 1.8148 | 4.2115 | | |
| **75%** | 3.0638 | 2.2041 | 5.0502 | | |
| **90%** | 4.0817 | 2.5411 | 5.8931 | | |
| **95%** | 4.7825 | 2.7356 | 6.4387 | | |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Triangle | Weibull | NA | |
| **No. Tests** | 6 | 6 | 6 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | 0.0486 | +Inf | | |
| **Mean** | 0.0277 | 0.0252 | 0.0383 | | |
| **Mode** | 0.0228 | 0.027 | 0.029 | | |
| **Std Dev** | 0.014 | 0.00995 | 0.0211 | | |
| **Alpha (α)** | 2.0757 | NA | 1.8874 | | |
| **Beta (β)** | 0.0312 | NA | 0.0432 | | |
| **Percentile** | | | | | |
| **5%** | 0.00747 | 0.0081 | 0.00895 | NA | |
| **10%** | 0.0106 | 0.0114 | 0.0131 | | |
| **25%** | 0.0171 | 0.0181 | 0.0223 | | |
| **50%** | 0.0262 | 0.0256 | 0.0356 | | |
| **75%** | 0.0366 | 0.0324 | 0.0514 | | |
| **90%** | 0.0467 | 0.0384 | 0.0672 | | |
| **95%** | 0.053 | 0.0414 | 0.0773 | | |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Triangle | Triangle | Gamma | NA | |
| **No. Tests** | 6 | 6 | 6 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | 54.057 | 42.621 | +Inf | | |
| **Mean** | 27.750 | 23.881 | 43.034 | | |
| **Mode** | 29.194 | 29.021 | 42.587 | | |
| **Std Dev** | 11.046 | 8.888 | 4.3888 | | |
| **Alpha (α)** | NA | NA | 96.146 | | |
| **Beta (β)** | NA | NA | 0.4476 | | |
| **Percentile** | | | | | |
| **5%** | 8.883 | 7.8641 | 36.078 | NA | |
| **10%** | 12.562 | 11.122 | 37.514 | | |
| **25%** | 19.863 | 17.585 | 39.998 | | |
| **50%** | 28.091 | 24.869 | 42.885 | | |
| **75%** | 35.727 | 30.583 | 45.908 | | |
| **90%** | 42.464 | 35.007 | 48.746 | | |
| **95%** | 45.859 | 37.237 | 50.498 | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min.** | NA | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Foam and Fabric Combinations – All Tests

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Weibull | Lognorm | NA | |
| **No. Tests** | 23 | 23 | 23 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 2.1275 | 1.6588 | 2.9065 | | |
| **Mode** | 1.8937 | 1.6476 | 2.6827 | | |
| **Std Dev** | 0.9645 | 0.5687 | 0.6809 | | |
| **Alpha (α)** | 2.344 | 3.2017 | NA | | |
| **Beta (β)** | 2.401 | 1.852 | NA | | |
| **Percentile** | | | | | |
| **5%** | 0.6761 | 0.7324 | 1.9349 | NA | |
| **10%** | 0.9192 | 0.917 | 2.1044 | | |
| **25%** | 1.411 | 1.255 | 2.4214 | | |
| **50%** | 2.0533 | 1.6517 | 2.8299 | | |
| **75%** | 2.7599 | 2.0509 | 3.3073 | | |
| **90%** | 3.427 | 2.4031 | 3.8055 | | |
| **95%** | 3.8341 | 2.6089 | 4.1388 | | |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Weibull | Weibull | NA | |
| **No. Tests** | 23 | 23 | 23 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | +Inf | +Inf | +Inf | | |
| **Mean** | 0.0173 | 0.0162 | 0.0191 | | |
| **Mode** | 0.00561 | 0.00951 | 0.00142 | | |
| **Std Dev** | 0.0136 | 0.0105 | 0.0179 | | |
| **Alpha (α)** | 1.2757 | 1.5762 | 1.065 | | |
| **Beta (β)** | 0.0186 | 0.01801 | 0.0195 | | |
| **Percentile** | | | | | |
| **5%** | 0.00182 | 0.00274 | 0.0012 | NA | |
| **10%** | 0.00319 | 0.00432 | 0.00236 | | |
| **25%** | 0.00702 | 0.00817 | 0.00607 | | |
| **50%** | 0.014 | 0.0143 | 0.0139 | | |
| **75%** | 0.0241 | 0.0222 | 0.0266 | | |
| **90%** | 0.0358 | 0.0306 | 0.0427 | | |
| **95%** | 0.044 | 0.0361 | 0.0547 | | |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Triangle | Triangle | Lognorm | NA | |
| **No. Tests** | 23 | 23 | 23 | NA | |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | NA | |
| **Max.** | 51.554 | 42.5719 | +Inf | | |
| **Mean** | 24.900 | 18.7618 | 28.3238 | | |
| **Mode** | 23.145 | 13.7134 | 26.2705 | | |
| **Std Dev** | 10.542 | 8.8714 | 6.4245 | | |
| **Alpha (α)** | NA | NA | NA | | |
| **Beta (β)** | NA | NA | NA | | |
| **Percentile** | | | | | |
| **5%** | 7.7241 | 5.4028 | 19.1097 | NA | |
| **10%** | 10.924 | 7.6407 | 20.7297 | | |
| **25%** | 17.272 | 12.0811 | 23.749 | | |
| **50%** | 24.493 | 17.7872 | 27.6221 | | |
| **75%** | 32.419 | 25.0465 | 32.1268 | | |
| **90%** | 39.452 | 31.4879 | 36.8061 | | |
| **95%** | 42.997 | 34.7343 | 39.9264 | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min.** | NA | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Foam and Fabric Combinations – Purpose-Built Chairs (Non-Fire Retardant Treated Polyurethane Foam with Polyester Wadding Overlay and Polyester Covering Fabric)

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Weibull | Gamma | Weibull | NA | |
| No. Tests | 11 | 11 | 11 | NA | |
| Parameter | | | | | |
| Min | 0 | 0 | 0 | NA | |
| Max | +Inf | +Inf | +Inf | | |
| Mean | 2.452 | 2.7243 | 2.382 | | |
| Mode | 2.448 | 2.5719 | 2.360 | | |
| Std Dev | 0.821 | 0.6444 | 0.825 | | |
| Alpha (α) | 3.286 | 17.872 | 3.165 | | |
| Beta (β) | 2.734 | 0.1524 | 2.661 | | |
| Percentile | | | | | |
| 5% | 1.107 | 1.7578 | 1.041 | NA | |
| 10% | 1.378 | 1.938 | 1.307 | | |
| 25% | 1.871 | 2.2666 | 1.795 | | |
| 50% | 2.446 | 2.6737 | 2.37 | | |
| 75% | 3.020 | 3.127 | 2.950 | | |
| 90% | 3.524 | 3.5759 | 3.463 | | |
| 95% | 3.818 | 3.8637 | 3.763 | | |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Triangle | Gamma | Triangle | NA | |
| No. Tests | 11 | 11 | 11 | NA | |
| Parameter | | | | | |
| Min | 0 | 0 | 0 | NA | |
| Max | 0.0295 | +Inf | 0.0244 | | |
| Mean | 0.0108 | 0.0136 | 0.00901 | | |
| Mode | 0.00286 | 0.0103 | 0.00264 | | |
| Std Dev | 0.00665 | 0.00671 | 0.00547 | | |
| Alpha (α) | NA | 4.0866 | NA | | |
| Beta (β) | NA | 0.00332 | NA | | |
| Percentile | | | | | |
| 5% | 0.00205 | 0.00471 | 0.00179 | NA | |
| 10% | 0.0029 | 0.00599 | 0.00254 | | |
| 25% | 0.00522 | 0.00866 | 0.00444 | | |
| 50% | 0.00968 | 0.0125 | 0.00811 | | |
| 75% | 0.0155 | 0.0173 | 0.0129 | | |
| 90% | 0.0207 | 0.0226 | 0.0171 | | |
| 95% | 0.0233 | 0.0262 | 0.0192 | | |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Weibull | Gamma | Triangle | NA | |
| No. Tests | 11 | 11 | 11 | NA | |
| Parameter | | | | | |
| Min | 0 | 0 | 0 | NA | |
| Max | +Inf | +Inf | 50.130 | | |
| Mean | 25.592 | 29.290 | 24.652 | | |
| Mode | 23.029 | 24.849 | 23.826 | | |
| Std Dev | 11.388 | 11.406 | 10.237 | | |
| Alpha (α) | 2.393 | 6.5946 | NA | | |
| Beta (β) | 28.87 | 4.4415 | NA | | |
| Percentile | | | | | |
| 5% | 8.345 | 13.368 | 7.728 | NA | |
| 10% | 11.274 | 15.950 | 10.929 | | |
| 25% | 17.154 | 21.014 | 17.28 | | |
| 50% | 24.771 | 27.824 | 24.453 | | |
| 75% | 33.093 | 35.974 | 31.974 | | |
| 90% | 40.908 | 44.526 | 38.647 | | |
| 95% | 45.663 | 50.219 | 42.010 | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Triangle | Weibull | Expon | NA | |
| No. Tests | 11 | 11 | 11 | NA | |
| Parameter | | | | | |
| Min | 0 | 0 | 0 | NA | |
| Max | 0.0579 | +Inf | +Inf | | |
| Mean | 0.0196 | 0.0324 | 0.0163 | | |
| Mode | 0.00103 | 0.0333 | 0 | | |
| Std Dev | 0.0135 | 0.00922 | 0.0163 | | |
| Alpha (α) | NA | 3.9449 | NA | | |
| Beta (β) | NA | 0.03582 | 0.0164 | | |
| Percentile | | | | | |
| 5% | 0.00197 | 0.0169 | 0.00084 | NA | |
| 10% | 0.00346 | 0.0202 | 0.00172 | | |
| 25% | 0.0082 | 0.0261 | 0.0047 | | |
| 50% | 0.0173 | 0.0326 | 0.0113 | | |
| 75% | 0.0292 | 0.0389 | 0.0227 | | |
| 90% | 0.0397 | 0.0443 | 0.0376 | | |
| 95% | 0.045 | 0.0473 | 0.049 | | |

# Foam and Fabric Combinations – Real Sofa (Predominantly Foam Construction)

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Lognorm | Weibull | Lognorm | Weibull |
| **No. Tests** | 3 | 3 | 3 | 3 | 3 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.8797 | 2.1026 | 1.8262 | 1.8556 | 1.7884 |
| **Mode** | 1.8559 | 2.0625 | 1.8745 | 1.8519 | 1.8485 |
| **Std Dev** | 0.1736 | 0.239 | 0.1234 | 0.0682 | 0.1641 |
| **Alpha (α)** | NA | NA | 18.293 | NA | 13.301 |
| **Beta (β)** | NA | NA | 1.8803 | NA | 1.8594 |
| **Percentile** | | | | | |
| **5%** | 1.6084 | 1.7339 | 1.5985 | 1.7456 | 1.4873 |
| **10%** | 1.6631 | 1.8068 | 1.6626 | 1.769 | 1.57 |
| **25%** | 1.7589 | 1.9354 | 1.7565 | 1.809 | 1.6931 |
| **50%** | 1.8717 | 2.0891 | 1.843 | 1.8544 | 1.8089 |
| **75%** | 1.9918 | 2.255 | 1.9142 | 1.9009 | 1.9056 |
| **90%** | 2.1064 | 2.4156 | 1.968 | 1.9438 | 1.9797 |
| **95%** | 2.1781 | 2.5171 | 1.9965 | 1.9699 | 2.0193 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Weibull | Weibull | Lognorm | Lognorm |
| **No. Tests** | 3 | 3 | 3 | 3 | 3 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 0.0144 | 0.00921 | 0.0155 | 0.0127 | 0.0201 |
| **Mode** | 0.0144 | 0.00963 | 0.0158 | 0.0117 | 0.0198 |
| **Std Dev** | 0.00486 | 0.00175 | 0.00458 | 0.00308 | 0.00217 |
| **Alpha (α)** | 3.2661 | 6.1272 | 3.7733 | NA | NA |
| **Beta (β)** | 0.01608 | 0.00992 | 0.01714 | NA | NA |
| **Percentile** | | | | | |
| **5%** | 0.00648 | 0.00611 | 0.0078 | 0.00834 | 0.0168 |
| **10%** | 0.00807 | 0.00687 | 0.00944 | 0.0091 | 0.0174 |
| **25%** | 0.011 | 0.00809 | 0.0123 | 0.0105 | 0.0186 |
| **50%** | 0.0144 | 0.00934 | 0.0156 | 0.0124 | 0.02 |
| **75%** | 0.0178 | 0.0105 | 0.0187 | 0.0145 | 0.0215 |
| **90%** | 0.0208 | 0.0114 | 0.0214 | 0.0168 | 0.023 |
| **95%** | 0.0225 | 0.0119 | 0.0229 | 0.0183 | 0.0239 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Weibull | Lognorm | Lognorm | Gamma |
| **No. Tests** | 3 | 3 | 3 | 3 | 3 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 24.366 | 23.314 | 24.613 | 24.2006 | 25.314 |
| **Mode** | 24.161 | 24.173 | 24.4621 | 24.1347 | 25.1447 |
| **Std Dev** | 2.2331 | 2.4416 | 1.5774 | 1.0319 | 2.0703 |
| **Alpha (α)** | 119.05 | 11.577 | NA | NA | 149.5 |
| **Beta (β)** | 0.2047 | 24.362 | NA | NA | 0.1693 |
| **Percentile** | | | | | |
| **5%** | 20.813 | 18.849 | 22.108 | 22.542 | 22.008 |
| **10%** | 21.551 | 20.058 | 22.628 | 22.893 | 022.7 |
| **25%** | 22.825 | 21.876 | 23.525 | 23.493 | 23.889 |
| **50%** | 24.298 | 23.603 | 24.563 | 24.179 | 25.258 |
| **75%** | 25.832 | 25.059 | 25.647 | 24.884 | 26.678 |
| **90%** | 27.268 | 26.181 | 26.663 | 25.536 | 28.001 |
| **95%** | 28.151 | 26.783 | 27.290 | 25.934 | 28.813 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Lognorm | Weibull | Lognorm | Triangle |
| **No. Tests** | 3 | 3 | 3 | 3 | 3 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | +Inf | +Inf | 0.0231 |
| **Mean** | 0.0174 | 0.023 | 0.0162 | 0.01703 | 0.0137 |
| **Mode** | 0.0163 | 0.022 | 0.0169 | 0.0169 | 0.0179 |
| **Std Dev** | 0.00445 | 0.00386 | 0.00249 | 0.00129 | 0.00495 |
| **Alpha (α)** | 15.307 | NA | 7.7228 | NA | NA |
| **Beta (β)** | 0.00114 | NA | 0.01724 | NA | NA |
| **Percentile** | | | | | |
| **5%** | 0.0108 | 0.0172 | 0.0117 | 0.015 | 0.00455 |
| **10%** | 0.012 | 0.0183 | 0.0129 | 0.01541 | 0.00643 |
| **25%** | 0.0142 | 0.0202 | 0.0147 | 0.0161 | 0.0102 |
| **50%** | 0.017 | 0.0227 | 0.0164 | 0.0170 | 0.0144 |
| **75%** | 0.0202 | 0.0254 | 0.018 | 0.0179 | 0.0176 |
| **90%** | 0.0233 | 0.0281 | 0.0192 | 0.0187 | 0.0196 |
| **95%** | 0.0253 | 0.0298 | 0.0199 | 0.0192 | 0.0206 |

# Foam and Fabric Combinations – All Tests

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Lognorm | Lognorm | Gamma | Weibull |
| **No. Tests** | 14 | 14 | 14 | 14 | 3 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 2.180 | 2.438 | 2.116 | 2.176 | 1.788 |
| **Mode** | 1.870 | 2.266 | 1.796 | 1.936 | 1.849 |
| **Std Dev** | 0.715 | 0.545 | 0.719 | 0.723 | 0.164 |
| **Alpha (α)** | NA | NA | NA | 9.071 | 13.30 |
| **Beta (β)** | NA | NA | NA | 0.240 | 1.859 |
| **Percentile** | | | | | |
| **5%** | 1.224 | 1.655 | 1.163 | 1.139 | 1.487 |
| **10%** | 1.375 | 1.793 | 1.312 | 1.317 | 1.57 |
| **25%** | 1.670 | 2.050 | 1.603 | 1.656 | 1.693 |
| **50%** | 2.071 | 2.380 | 2.003 | 2.097 | 1.809 |
| **75%** | 2.570 | 2.762 | 2.503 | 2.611 | 1.906 |
| **90%** | 3.120 | 3.159 | 3.060 | 3.139 | 1.980 |
| **95%** | 3.504 | 3.423 | 3.450 | 3.485 | 2.019 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Lognorm | Triangle | Triangle | Lognorm |
| **No. Tests** | 14 | 14 | 14 | 14 | 3 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | 0.0283 | 0.0234 | +Inf |
| **Mean** | 0.0128 | 0.0117 | 0.0136 | 0.0112 | 0.0201 |
| **Mode** | 0.0112 | 0.0084 | 0.0123 | 0.0103 | 0.0198 |
| **Std Dev** | 0.00591 | 0.00578 | 0.0058 | 0.00478 | 0.00217 |
| **Alpha (α)** | 2.291 | NA | NA | NA | NA |
| **Beta (β)** | 0.0144 | NA | NA | NA | NA |
| **Percentile** | | | | | |
| **5%** | 0.0039 | 0.00484 | 0.00418 | 0.00348 | 0.0168 |
| **10%** | 0.00539 | 0.00574 | 0.00591 | 0.00492 | 0.0174 |
| **25%** | 0.00836 | 0.00763 | 0.00935 | 0.00778 | 0.0186 |
| **50%** | 0.0123 | 0.0105 | 0.0133 | 0.011 | 0.02 |
| **75%** | 0.0166 | 0.0144 | 0.0177 | 0.0147 | 0.0215 |
| **90%** | 0.0207 | 0.0191 | 0.0216 | 0.0179 | 0.023 |
| **95%** | 0.0233 | 0.0226 | 0.0236 | 0.0195 | 0.0239 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Lognorm | Triangle | Weibull | Gamma |
| **No. Tests** | 14 | 14 | 14 | 14 | 3 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | 50.127 | +Inf | +Inf |
| **Mean** | 24.860 | 26.521 | 24.635 | 24.334 | 25.314 |
| **Mode** | 24.634 | 22.543 | 23.776 | 23.802 | 25.145 |
| **Std Dev** | 8.609 | 8.972 | 10.237 | 8.848 | 2.0703 |
| **Alpha (α)** | 3.166 | NA | NA | 2.998 | 149.5 |
| **Beta (β)** | 27.771 | NA | NA | 27.251 | 0.1693 |
| **Percentile** | | | | | |
| **5%** | 10.869 | 14.619 | 7.7195 | 10.120 | 22.008 |
| **10%** | 13.643 | 16.476 | 10.917 | 12.865 | 22.700 |
| **25%** | 18.737 | 20.121 | 17.261 | 17.985 | 23.889 |
| **50%** | 24.735 | 25.123 | 24.428 | 24.115 | 25.258 |
| **75%** | 30.789 | 31.368 | 31.955 | 30.39 | 26.678 |
| **90%** | 36.140 | 38.306 | 38.634 | 35.99 | 28.001 |
| **95%** | 39.272 | 43.173 | 42.000 | 39.292 | 28.813 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Lognorm | Weibull | Weibull | Triangle |
| **No. Tests** | 14 | 14 | 14 | 14 | 3 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | +Inf | +Inf | 0.0231 |
| **Mean** | 0.0185 | 0.0282 | 0.0162 | 0.0166 | 0.0137 |
| **Mode** | 0.012 | 0.0248 | 0.00946 | 0.00805 | 0.0179 |
| **Std Dev** | 0.0114 | 0.00839 | 0.0106 | 0.0117 | 0.00495 |
| **Alpha (α)** | 1.666 | NA | 1.568 | 1.442 | NA |
| **Beta (β)** | 0.0207 | NA | 0.0181 | 0.0183 | NA |
| **Percentile** | | | | | |
| **5%** | 0.00349 | 0.0167 | 0.00272 | 0.00233 | 0.00455 |
| **10%** | 0.00537 | 0.0186 | 0.0043 | 0.00384 | 0.00643 |
| **25%** | 0.00982 | 0.0222 | 0.00817 | 0.0077 | 0.0102 |
| **50%** | 0.0166 | 0.027 | 0.0143 | 0.0142 | 0.0144 |
| **75%** | 0.0252 | 0.0329 | 0.0223 | 0.0229 | 0.0176 |
| **90%** | 0.0342 | 0.0392 | 0.0308 | 0.0326 | 0.0196 |
| **95%** | 0.0401 | 0.0436 | 0.0364 | 0.0391 | 0.0206 |

# Beds – King Size Innerspring Mattress (49% Blended Cotton Felt and 51% Polyurethane Foam) on Wooden Framed, Box Spring Foundation

| $CO_2$ Yield (kg/kg) | | | | | | CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Lognorm | Gamma | Lognorm | Gamma | **Distrib.** | Lognorm | Weibull | Uniform | Triangle | Lognorm |
| **No. Tests** | 2 | 2 | 2 | 2 | 1 | **No. Tests** | 2 | 2 | 2 | 2 | 1 |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 | **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf | **Max.** | +Inf | +Inf | 0.1507 | 0.1668 | +Inf |
| **Mean** | 2.3671 | 1.7469 | 2.8828 | 2.8468 | 3.2261 | **Mean** | 0.0395 | 0.0115 | 0.0753 | 0.057 | 0.1427 |
| **Mode** | 2.055 | 1.6982 | 2.7429 | 2.6302 | 3.2242 | **Mode** | 0.00713 | 0.012 | 0 | 0.00422 | 0.1426 |
| **Std Dev** | 0.7442 | 0.241 | 0.6351 | 0.6626 | 0.0791 | **Std Dev** | 0.0576 | 0.00267 | 0.0435 | 0.0388 | 0.00383 |
| **Alpha (α)** | NA | NA | 20.603 | NA | 1661.9 | **Alpha (α)** | NA | 4.9371 | NA | NA | NA |
| **Beta (β)** | NA | NA | 0.1399 | NA | 0.0019412 | **Beta (β)** | NA | 0.012553 | NA | NA | NA |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 1.3628 | 1.3807 | 1.9235 | 1.9003 | 3.0971 | **5%** | 0.00385 | 0.00688 | 0.00753 | 0.00629 | 0.1365 |
| **10%** | 1.5236 | 1.4513 | 2.1047 | 2.0657 | 3.1251 | **10%** | 0.00568 | 0.00796 | 0.0151 | 0.0106 | 0.1379 |
| **25%** | 1.8357 | 1.5775 | 2.4329 | 2.3748 | 3.1724 | **25%** | 0.0109 | 0.00975 | 0.0377 | 0.0242 | 0.1401 |
| **50%** | 2.2581 | 1.7305 | 2.8363 | 2.7727 | 3.2255 | **50%** | 0.0223 | 0.0117 | 0.0753 | 0.0504 | 0.1427 |
| **75%** | 2.7776 | 1.8984 | 3.2821 | 3.2373 | 3.2791 | **75%** | 0.0459 | 0.0134 | 0.113 | 0.0845 | 0.1453 |
| **90%** | 3.3467 | 2.0635 | 3.7208 | 3.7217 | 3.3279 | **90%** | 0.0877 | 0.0149 | 0.1356 | 0.1147 | 0.1477 |
| **95%** | 3.7415 | 2.169 | 4.0008 | 4.0455 | 3.3574 | **95%** | 0.1293 | 0.0157 | 0.1431 | 0.13 | 0.1491 |

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Lognorm | Gamma | Lognorm | Lognorm | **Distrib.** | NA | | | | |
| **No. Tests** | 2 | 2 | 2 | 2 | 1 | **No. Tests** | NA | | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 | **Min.** | NA | | | | |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf | **Max.** | | | | | |
| **Mean** | 21.523 | 16.196 | 25.921 | 26.232 | 22.986 | **Mean** | | | | | |
| **Mode** | 19.557 | 14.692 | 25.461 | 25.542 | 22.90 | **Mode** | | | | | |
| **Std Dev** | 6.506 | 4.195 | 3.453 | 3.511 | 1.151 | **Std Dev** | | | | | |
| **Alpha (α)** | 10.944 | NA | 56.35 | NA | NA | **Alpha (α)** | | | | | |
| **Beta (β)** | 1.967 | NA | 0.4600 | NA | NA | **Beta (β)** | | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 12.05 | 10.311 | 20.515 | 20.883 | 21.143 | **5%** | NA | | | | |
| **10%** | 13.719 | 11.310 | 21.606 | 21.918 | 21.531 | **10%** | | | | | |
| **25%** | 16.854 | 13.202 | 23.516 | 23.765 | 22.195 | **25%** | | | | | |
| **50%** | 20.871 | 15.678 | 25.768 | 26.000 | 22.957 | **50%** | | | | | |
| **75%** | 25.484 | 18.619 | 28.159 | 28.445 | 23.745 | **75%** | | | | | |
| **90%** | 30.168 | 21.734 | 30.433 | 30.841 | 24.478 | **90%** | | | | | |
| **95%** | 33.221 | 23.842 | 31.850 | 32.371 | 24.927 | **95%** | | | | | |

# Sleeper Sofas – Polyester Fabric Covered Polyurethane Foam on Wooden Frame

| $CO_2$ Yield (kg/kg) | | | | | | CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Weibull | Lognorm | Lognorm | Lognorm | **Distrib.** | Triangle | Weibull | Triangle | Lognorm | Lognorm |
| **No. Tests** | 2 | 2 | 2 | 2 | 1 | **No. Tests** | 2 | 2 | 2 | 2 | 1 |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 | **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf | **Max.** | 0.0699 | +Inf | 0.0718 | +Inf | +Inf |
| **Mean** | 2.039 | 1.7093 | 2.1453 | 2.0844 | 2.3097 | **Mean** | 0.0287 | 0.0166 | 0.0313 | 0.0278 | 0.0497 |
| **Mode** | 1.9599 | 1.7841 | 2.1106 | 2.0579 | 2.277 | **Mode** | 0.0161 | 0.0173 | 0.022 | 0.0206 | 0.0489 |
| **Std Dev** | 0.3334 | 0.2454 | 0.2242 | 0.1931 | 0.2256 | **Std Dev** | 0.0149 | 0.00302 | 0.015 | 0.013 | 0.00523 |
| **Alpha (α)** | NA | 8.2867 | NA | NA | NA | **Alpha (α)** | NA | NA | NA | NA | NA |
| **Beta (β)** | NA | 1.812 | NA | NA | NA | **Beta (β)** | NA | NA | NA | NA | NA |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 1.5405 | 1.2662 | 1.7975 | 1.7828 | 1.9583 | **5%** | 0.00749 | 0.0112 | 0.00889 | 0.0121 | 0.0416 |
| **10%** | 1.6342 | 1.3811 | 1.8669 | 1.8437 | 2.0288 | **10%** | 0.0106 | 0.0125 | 0.0126 | 0.0142 | 0.0432 |
| **25%** | 1.8035 | 1.5591 | 1.9888 | 1.9501 | 2.1525 | **25%** | 0.0168 | 0.0146 | 0.0199 | 0.0186 | 0.0461 |
| **50%** | 2.0123 | 1.7336 | 2.1336 | 2.0755 | 2.2987 | **50%** | 0.0265 | 0.0168 | 0.0295 | 0.0252 | 0.0495 |
| **75%** | 2.2453 | 1.8849 | 2.289 | 2.209 | 2.4549 | **75%** | 0.0392 | 0.0187 | 0.0419 | 0.034 | 0.0531 |
| **90%** | 2.478 | 2.0039 | 2.4385 | 2.3365 | 2.6045 | **90%** | 0.0505 | 0.0203 | 0.0529 | 0.0446 | 0.0566 |
| **95%** | 2.6286 | 2.0685 | 2.5326 | 2.4163 | 2.6984 | **95%** | 0.0562 | 0.0211 | 0.0584 | 0.0524 | 0.0588 |

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Triangle | Lognorm | Lognorm | Lognorm | **Distrib.** | NA | | | | |
| **No. Tests** | 2 | 2 | 2 | 2 | 1 | **No. Tests** | NA | | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 | **Min.** | NA | | | | |
| **Max.** | +Inf | 21.5462 | +Inf | +Inf | +Inf | **Max.** | | | | | |
| **Mean** | 16.9191 | 14.3641 | 17.0005 | 17.116 | 16.6889 | **Mean** | | | | | |
| **Mode** | 16.4465 | 21.5462 | 16.7983 | 16.9219 | 16.4771 | **Mode** | | | | | |
| **Std Dev** | 2.8278 | 5.0785 | 1.5215 | 1.495 | 1.5432 | **Std Dev** | | | | | |
| **Alpha (α)** | 35.799 | NA | NA | NA | NA | **Alpha (α)** | | | | | |
| **Beta (β)** | 0.47261 | NA | NA | NA | NA | **Beta (β)** | | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 12.5516 | 4.8179 | 14.6193 | 14.7732 | 14.2779 | **5%** | NA | | | | |
| **10%** | 13.4114 | 6.8135 | 15.1014 | 15.2486 | 14.7646 | **10%** | | | | | |
| **25%** | 14.9359 | 10.7731 | 15.9429 | 16.0773 | 15.6153 | **25%** | | | | | |
| **50%** | 16.7619 | 15.2354 | 16.9328 | 17.051 | 16.618 | **50%** | | | | | |
| **75%** | 18.7311 | 18.6595 | 17.9843 | 18.0837 | 17.6852 | **75%** | | | | | |
| **90%** | 20.6291 | 20.4405 | 18.9864 | 19.0665 | 18.7041 | **90%** | | | | | |
| **95%** | 21.8232 | 21.0006 | 19.6126 | 19.68 | 19.3417 | **95%** | | | | | |

# Polypropylene Trash Containers

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Weibull | NA | | | |
| No. Tests | 2 | NA | | | |
| Parameter | | | | | |
| Min. | 0 | NA | | | |
| Max. | +Inf | | | | |
| Mean | 2.5875 | | | | |
| Mode | 2.7043 | | | | |
| Std Dev | 0.4087 | | | | |
| Alpha (α) | 7.4811 | | | | |
| Beta (β) | 2.7567 | | | | |
| Percentile | | | | | |
| 5% | 1.8534 | NA | | | |
| 10% | 2.0406 | | | | |
| 25% | 2.3338 | | | | |
| 50% | 2.6249 | | | | |
| 75% | 2.8797 | | | | |
| 90% | 3.0818 | | | | |
| 95% | 3.1921 | | | | |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Gamma | NA | | | |
| No. Tests | 2 | NA | | | |
| Parameter | | | | | |
| Min. | 0 | NA | | | |
| Max. | +Inf | | | | |
| Mean | 0.0273 | | | | |
| Mode | 0.0176 | | | | |
| Std Dev | 0.0163 | | | | |
| Alpha (α) | NA | | | | |
| Beta (β) | NA | | | | |
| Percentile | | | | | |
| 5% | 0.007 | NA | | | |
| 10% | 0.00958 | | | | |
| 25% | 0.0153 | | | | |
| 50% | 0.0242 | | | | |
| 75% | 0.0359 | | | | |
| 90% | 0.0492 | | | | |
| 95% | 0.0585 | | | | |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Weibull | NA | | | |
| No. Tests | 2 | NA | | | |
| Parameter | | | | | |
| Min. | 0 | NA | | | |
| Max. | +Inf | | | | |
| Mean | 21.469 | | | | |
| Mode | 22.3747 | | | | |
| Std Dev | 4.8444 | | | | |
| Alpha (α) | NA | | | | |
| Beta (β) | NA | | | | |
| Percentile | | | | | |
| 5% | 13.0222 | NA | | | |
| 10% | 15.0034 | | | | |
| 25% | 18.2818 | | | | |
| 50% | 21.735 | | | | |
| 75% | 24.9108 | | | | |
| 90% | 27.526 | | | | |
| 95% | 28.9887 | | | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | NA | | | | |
| No. Tests | NA | | | | |
| | | | | | |
| Min. | NA | | | | |
| Max. | | | | | |
| Mean | | | | | |
| Mode | | | | | |
| Std Dev | | | | | |
| Alpha (α) | | | | | |
| Beta (β) | | | | | |
| | | | | | |
| 5% | NA | | | | |
| 10% | | | | | |
| 25% | | | | | |
| 50% | | | | | |
| 75% | | | | | |
| 90% | | | | | |
| 95% | | | | | |

# Upholstered Chairs – Polyurethane Foam on Wooden Frame

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Gamma | Gamma | Lognorm | NA | |
| No. Tests | 2 | 2 | 2 | NA | |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | NA | |
| Max. | +Inf | +Inf | +Inf | | |
| Mean | 2.4672 | 2.2106 | 2.5866 | | |
| Mode | 2.367 | 2.0841 | 2.4992 | | |
| Std Dev | 0.4972 | 0.5288 | 0.394 | | |
| Alpha (α) | 24.622 | 17.475 | 2.5866 | | |
| Beta (β) | 0.10021 | 0.1265 | 0.39396 | | |
| Percentile | | | | | |
| 5% | 1.7102 | 1.4184 | 1.9933 | NA | |
| 10% | 1.8553 | 1.5657 | 2.1061 | | |
| 25% | 2.1162 | 1.8348 | 2.3089 | | |
| 50% | 2.4339 | 2.1686 | 2.5572 | | |
| 75% | 2.782 | 2.5407 | 2.8321 | | |
| 90% | 3.1221 | 2.9096 | 3.1048 | | |
| 95% | 3.338 | 3.1462 | 3.2805 | | |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Gamma | Weibull | Weibull | NA | |
| No. Tests | 2 | 2 | 2 | NA | |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | NA | |
| Max. | +Inf | +Inf | +Inf | | |
| Mean | 0.0314 | 0.0173 | 0.0381 | | |
| Mode | 0.0201 | 0.0169 | 0.0317 | | |
| Std Dev | 0.0188 | 0.00638 | 0.019 | | |
| Alpha (α) | 2.7873 | NA | NA | | |
| Beta (β) | 0.011258 | NA | NA | | |
| Percentile | | | | | |
| 5% | 0.008 | 0.00709 | 0.0105 | NA | |
| 10% | 0.011 | 0.00905 | 0.0148 | | |
| 25% | 0.0176 | 0.0127 | 0.0238 | | |
| 50% | 0.0277 | 0.0171 | 0.0362 | | |
| 75% | 0.0412 | 0.0217 | 0.0502 | | |
| 90% | 0.0566 | 0.0257 | 0.0639 | | |
| 95% | 0.0673 | 0.0281 | 0.0724 | | |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Lognorm | Lognorm | Lognorm | NA | |
| No. Tests | 2 | 2 | 2 | NA | |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | NA | |
| Max. | +Inf | +Inf | +Inf | | |
| Mean | 17.7177 | 16.8786 | 18.1147 | | |
| Mode | 17.1931 | 16.2555 | 17.69 | | |
| Std Dev | 2.5207 | 2.6896 | 2.2871 | | |
| Alpha (α) | NA | NA | NA | | |
| Beta (β) | NA | NA | NA | | |
| Percentile | | | | | |
| 5% | 13.8975 | 12.8461 | 14.6137 | NA | |
| 10% | 14.6309 | 13.6068 | 15.2968 | | |
| 25% | 15.9438 | 14.9798 | 16.5104 | | |
| 50% | 17.5411 | 16.6683 | 17.972 | | |
| 75% | 19.2985 | 18.5471 | 19.563 | | |
| 90% | 21.0302 | 20.4186 | 21.115 | | |
| 95% | 22.14 | 21.6277 | 22.1021 | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | NA | | | | |
| No. Tests | NA | | | | |
| Parameter | | | | | |
| Min. | NA | | | | |
| Max. | | | | | |
| Mean | | | | | |
| Mode | | | | | |
| Std Dev | | | | | |
| Alpha (α) | | | | | |
| Beta (β) | | | | | |
| Percentile | | | | | |
| 5% | NA | | | | |
| 10% | | | | | |
| 25% | | | | | |
| 50% | | | | | |
| 75% | | | | | |
| 90% | | | | | |
| 95% | | | | | |

# All Tests

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Lognorm | Lognorm | Lognorm | Lognorm |
| **No. Tests** | 8 | 8 | 8 | 6 | 2 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 2.2808 | 2.0131 | 2.4382 | 2.3854 | 2.4363 |
| **Mode** | 2.1017 | 1.8422 | 2.3088 | 2.2675 | 2.3573 |
| **Std Dev** | 0.5399 | 0.497 | 0.4691 | 0.4424 | 0.3633 |
| **Alpha (α)** | NA | NA | NA | NA | NA |
| **Beta (β)** | NA | NA | NA | NA | NA |
| **Percentile** | | | | | |
| **5%** | 1.5116 | 1.31 | 1.7497 | 1.7333 | 1.888 |
| **10%** | 1.6455 | 1.431 | 1.8752 | 1.8531 | 1.9926 |
| **25%** | 1.896 | 1.6587 | 2.1053 | 2.0719 | 2.1803 |
| **50%** | 2.2194 | 1.9544 | 2.3942 | 2.3455 | 2.4097 |
| **75%** | 2.598 | 2.3029 | 2.7228 | 2.6552 | 2.6632 |
| **90%** | 2.9936 | 2.6694 | 3.057 | 2.9687 | 2.9141 |
| **95%** | 3.2586 | 2.916 | 3.2762 | 3.1738 | 3.0755 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Lognorm | Lognorm | Lognorm | Lognorm |
| **No. Tests** | 8 | 8 | 8 | 6 | 2 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 0.0325 | 0.0173 | 0.0425 | 0.0385 | 0.0616 |
| **Mode** | 0.0144 | 0.0122 | 0.0196 | 0.0178 | 0.0496 |
| **Std Dev** | 0.0276 | 0.00882 | 0.0348 | 0.0316 | 0.0242 |
| **Alpha (α)** | NA | NA | NA | NA | NA |
| **Beta (β)** | NA | NA | NA | NA | NA |
| **Percentile** | | | | | |
| **5%** | 0.00736 | 0.00698 | 0.0101 | 0.00914 | 0.0307 |
| **10%** | 0.00962 | 0.00831 | 0.0131 | 0.0119 | 0.0352 |
| **25%** | 0.0151 | 0.0111 | 0.0203 | 0.0183 | 0.0444 |
| **50%** | 0.0248 | 0.0154 | 0.0329 | 0.0298 | 0.0573 |
| **75%** | 0.0407 | 0.0213 | 0.0533 | 0.0483 | 0.074 |
| **90%** | 0.0637 | 0.0285 | 0.0824 | 0.0747 | 0.0932 |
| **95%** | 0.0832 | 0.034 | 0.1069 | 0.097 | 0.107 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Gamma | Lognorm | Lognorm | Lognorm |
| **No. Tests** | 8 | 8 | 8 | 6 | 2 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 18.6293 | 17.527 | 19.2622 | 19.5665 | 17.5589 |
| **Mode** | 17.1621 | 16.3126 | 18.1515 | 18.3829 | 17.0351 |
| **Std Dev** | 4.4167 | 4.6136 | 3.8711 | 4.0326 | 2.5076 |
| **Alpha (α)** | NA | 14.432 | NA | NA | NA |
| **Beta (β)** | NA | 1.2144 | NA | NA | NA |
| **Percentile** | | | | | |
| **5%** | 12.3387 | 10.6884 | 13.6133 | 13.702 | 13.7598 |
| **10%** | 13.4328 | 11.935 | 14.6339 | 14.7558 | 14.4888 |
| **25%** | 15.4817 | 14.2351 | 16.5128 | 16.7007 | 15.794 |
| **50%** | 18.1268 | 17.1239 | 18.8847 | 19.1637 | 17.3826 |
| **75%** | 21.2238 | 20.3801 | 21.5972 | 21.9899 | 19.1309 |
| **90%** | 24.4611 | 23.6383 | 24.3701 | 24.8883 | 20.8543 |
| **95%** | 26.6301 | 25.741 | 26.1971 | 26.8025 | 21.9591 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min.** | NA | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Foam and Fabric Combinations – Non-Fire Retarded Foams

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Gamma | Weibull | Weibull | Weibull |
| **No. Tests** | 6 | 6 | 6 | 6 | 2 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.5771 | 1.1668 | 1.9207 | 1.9217 | 1.9174 |
| **Mode** | 1.585 | 1.0569 | 2.0082 | 2.0087 | 1.9932 |
| **Std Dev** | 0.5115 | 0.358 | 0.3743 | 0.3842 | 0.2248 |
| **Alpha (α)** | 3.4054 | 10.624 | 5.963 | 5.8 | 10.276 |
| **Beta (β)** | 1.7553 | 0.10983 | 2.071 | 2.075 | 2.0131 |
| **Percentile** | | | | | |
| **5%** | 0.7338 | 0.6466 | 1.2585 | 1.2436 | 1.5078 |
| **10%** | 0.9065 | 0.7379 | 1.42 | 1.408 | 1.6172 |
| **25%** | 1.2175 | 0.9097 | 1.6805 | 1.6742 | 1.7833 |
| **50%** | 1.5762 | 1.1304 | 1.9476 | 1.9483 | 1.9426 |
| **75%** | 1.932 | 1.3843 | 2.1876 | 2.1956 | 2.0781 |
| **90%** | 2.2424 | 1.6426 | 2.3819 | 2.3963 | 2.1833 |
| **95%** | 2.4226 | 1.8111 | 2.4894 | 2.5075 | 2.24 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Gamma | Triangle | Gamma | Weibull |
| **No. Tests** | 6 | 6 | 6 | 6 | 2 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | 0.0816 | +Inf | +Inf |
| **Mean** | 0.0161 | 0.00438 | 0.028 | 0.0245 | 0.0561 |
| **Mode** | 0.00289 | 0.00398 | 0.00253 | 0.00524 | 0.0583 |
| **Std Dev** | 0.0236 | 0.00133 | 0.0189 | 0.0217 | 0.00671 |
| **Alpha (α)** | NA | 10.932 | NA | 1.272 | 10.058 |
| **Beta (β)** | NA | 0.000401 | NA | 0.0193 | 0.0589 |
| **Percentile** | | | | | |
| **5%** | 0.00156 | 0.00245 | 0.00331 | 0.00214 | 0.0439 |
| **10%** | 0.00231 | 0.00279 | 0.00539 | 0.00383 | 0.0471 |
| **25%** | 0.00442 | 0.00343 | 0.012 | 0.00876 | 0.0521 |
| **50%** | 0.0091 | 0.00425 | 0.0248 | 0.0185 | 0.0568 |
| **75%** | 0.0187 | 0.00519 | 0.0414 | 0.0338 | 0.0609 |
| **90%** | 0.0358 | 0.00614 | 0.0562 | 0.0532 | 0.064 |
| **95%** | 0.0529 | 0.00676 | 0.0636 | 0.0675 | 0.0657 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Weibull | Lognorm | Lognorm | Gamma |
| **No. Tests** | 6 | 6 | 6 | 6 | 2 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 16.2684 | 16.5841 | 15.9955 | 16.1912 | 14.0656 |
| **Mode** | 15.0045 | 17.1921 | 15.0706 | 15.2148 | 13.9508 |
| **Std Dev** | 3.829 | 4.1582 | 3.2194 | 3.3316 | 1.2704 |
| **Alpha (α)** | NA | 4.528 | NA | NA | 122.59 |
| **Beta (β)** | NA | 18.166 | NA | NA | 0.115 |
| **Percentile** | | | | | |
| **5%** | 10.8084 | 9.4267 | 11.2986 | 11.3451 | 12.0432 |
| **10%** | 11.7598 | 11.0512 | 12.1469 | 12.2163 | 12.464 |
| **25%** | 13.54 | 13.7962 | 13.7089 | 13.8237 | 13.1891 |
| **50%** | 15.8357 | 16.7538 | 15.6811 | 15.859 | 14.0273 |
| **75%** | 18.5206 | 19.5255 | 17.9369 | 18.1939 | 14.9003 |
| **90%** | 21.3242 | 21.841 | 20.2435 | 20.5879 | 15.7162 |
| **95%** | 23.2012 | 23.1481 | 21.7634 | 22.1688 | 16.2183 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min** | NA | | | | |
| **Max** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Foam and Fabric Combinations – Fire Retarded Foams

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Gamma | Lognorm | Gamma | Weibull |
| **No. Tests** | 4 | 4 | 4 | 4 | 2 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.4772 | 1.146 | 1.7583 | 1.7995 | 1.5932 |
| **Mode** | 1.4222 | 0.8693 | 1.6168 | 1.6987 | 1.6636 |
| **Std Dev** | 0.5648 | 0.5632 | 0.4217 | 0.426 | 0.3376 |
| **Alpha (α)** | 2.8347 | 4.1408 | NA | 17.843 | 5.444 |
| **Beta (β)** | 1.6581 | 0.2768 | NA | 0.101 | 1.727 |
| **Percentile** | | | | | |
| **5%** | 0.5815 | 0.4009 | 1.1588 | 1.1606 | 1.0006 |
| **10%** | 0.7496 | 0.5091 | 1.2627 | 1.2797 | 1.1421 |
| **25%** | 1.0684 | 0.7338 | 1.4577 | 1.4969 | 1.3735 |
| **50%** | 1.457 | 1.0552 | 1.7098 | 1.766 | 1.6144 |
| **75%** | 1.8606 | 1.4599 | 2.0054 | 2.0657 | 1.8336 |
| **90%** | 2.2253 | 1.9008 | 2.3151 | 2.3625 | 2.0127 |
| **95%** | 2.4418 | 2.2013 | 2.5228 | 2.5527 | 2.1124 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Lognorm | Triangle | Gamma | Weibull |
| **No. Tests** | 4 | 4 | 4 | 4 | 2 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | 0.0714 | +Inf | +Inf |
| **Mean** | 0.0198 | 0.00973 | 0.026 | 0.0229 | 0.0466 |
| **Mode** | 0.00661 | 0.00558 | 0.00675 | 0.0116 | 0.0487 |
| **Std Dev** | 0.0205 | 0.00651 | 0.0161 | 0.0161 | 0.00877 |
| **Alpha (α)** | NA | NA | NA | 2.018 | 6.190 |
| **Beta (β)** | NA | NA | NA | 0.0114 | 0.0501 |
| **Percentile** | | | | | |
| **5%** | 0.00336 | 0.00297 | 0.00491 | 0.00412 | 0.031 |
| **10%** | 0.00459 | 0.00371 | 0.00694 | 0.00615 | 0.0349 |
| **25%** | 0.00771 | 0.00536 | 0.0126 | 0.0111 | 0.041 |
| **50%** | 0.0137 | 0.00808 | 0.0234 | 0.0193 | 0.0473 |
| **75%** | 0.0244 | 0.0122 | 0.0374 | 0.0309 | 0.0529 |
| **90%** | 0.0411 | 0.0176 | 0.0499 | 0.0445 | 0.0574 |
| **95%** | 0.056 | 0.022 | 0.0562 | 0.0542 | 0.0599 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Gamma | Lognorm | Lognorm | Weibull |
| **No. Tests** | 4 | 4 | 4 | 4 | 2 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | +Inf | +Inf | 20.4873 |
| **Mean** | 14.7286 | 15.2293 | 14.3108 | 14.9671 | 11.6874 |
| **Mode** | 13.4891 | 13.3911 | 13.2369 | 13.9846 | 12.2061 |
| **Std Dev** | 4.2727 | 5.2911 | 3.3064 | 3.2206 | 2.4531 |
| **Alpha (α)** | 11.883 | 8.2846 | NA | NA | 5.501 |
| **Beta (β)** | 1.2395 | 1.8383 | NA | NA | 12.66 |
| **Percentile** | | | | | |
| **5%** | 8.472 | 7.6883 | 9.5822 | 10.3117 | 7.3776 |
| **10%** | 9.5863 | 8.9628 | 10.4099 | 11.1403 | 8.409 |
| **25%** | 11.6674 | 11.4087 | 11.9556 | 12.6762 | 10.0937 |
| **50%** | 14.3176 | 14.6211 | 13.9435 | 14.6321 | 11.8435 |
| **75%** | 17.3427 | 18.3889 | 16.2619 | 16.8899 | 13.4341 |
| **90%** | 20.4007 | 22.2809 | 18.6765 | 19.2184 | 14.7322 |
| **95%** | 22.3879 | 24.8461 | 20.2897 | 20.7627 | 15.4541 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min** | NA | | | | |
| **Max** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Foam and Fabric Combinations – Domestic Foams

| $CO_2$ Yield (kg/kg) | | | | | | CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Weibull | Lognorm | Gamma | Gamma | **Distrib.** | Lognorm | Weibull | Triangle | Weibull | Gamma |
| **No. Tests** | 2 | 2 | 2 | 2 | 1 | **No. Tests** | 2 | 2 | 2 | 2 | 1 |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 | **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | +Inf | +Inf | +Inf | **Max** | +Inf | +Inf | 0.073 | +Inf | +Inf |
| **Mean** | 1.6374 | 1.3831 | 1.8454 | 1.8539 | 1.7042 | **Mean** | 0.0163 | 0.00542 | 0.0259 | 0.0242 | 0.06071 |
| **Mode** | 1.7101 | 1.4381 | 1.8101 | 1.8291 | 1.7042 | **Mode** | 0.0045 | 0.00559 | 0.00471 | 0.0116 | 0.06071 |
| **Std Dev** | 0.3434 | 0.3295 | 0.2103 | 0.2141 | 0.00728 | **Std Dev** | 0.019 | 0.00144 | 0.0167 | 0.0171 | 0.000403 |
| **Alpha (α)** | 5.505 | 4.7901 | NA | 74.97 | 54836 | **Alpha (α)** | NA | 4.2558 | NA | 1.434 | 22690 |
| **Beta (β)** | 1.774 | 1.5101 | NA | 0.0247 | 0.000031 | **Beta (β)** | NA | 0.005956 | NA | 0.0266 | 2.7 E-6 |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 1.034 | 0.8123 | 1.5211 | 1.5163 | 1.6923 | **5%** | 0.00231 | 0.00296 | 0.004 | 0.00336 | 0.06005 |
| **10%** | 1.1784 | 0.944 | 1.5852 | 1.5853 | 1.6949 | **10%** | 0.00324 | 0.00351 | 0.006 | 0.00554 | 0.06019 |
| **25%** | 1.4143 | 1.1643 | 1.6984 | 1.7053 | 1.6993 | **25%** | 0.00568 | 0.00444 | 0.012 | 0.0112 | 0.06044 |
| **50%** | 1.6593 | 1.3989 | 1.8336 | 1.8456 | 1.7042 | **50%** | 0.0106 | 0.00546 | 0.023 | 0.0206 | 0.06071 |
| **75%** | 1.8819 | 1.6167 | 1.9795 | 1.9934 | 1.7091 | **75%** | 0.0198 | 0.00643 | 0.038 | 0.0335 | 0.06098 |
| **90%** | 2.0636 | 1.7974 | 2.1208 | 2.133 | 1.7136 | **90%** | 0.0347 | 0.00725 | 0.051 | 0.0477 | 0.06123 |
| **95%** | 2.1647 | 1.8989 | 2.2102 | 2.2195 | 1.7162 | **95%** | 0.0486 | 0.00771 | 0.057 | 0.0573 | 0.06137 |

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Weibull | Lognorm | Lognorm | Gamma | **Distrib.** | NA | | | | |
| **No. Tests** | 2 | 2 | 2 | 2 | 1 | **No. Tests** | NA | | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 | **Min** | NA | | | | |
| **Max** | +Inf | +Inf | +Inf | +Inf | +Inf | **Max** | | | | | |
| **Mean** | 17.3672 | 18.6509 | 16.2725 | 16.4599 | 13.0905 | **Mean** | | | | | |
| **Mode** | 16.8432 | 19.5056 | 15.8698 | 16.0978 | 13.0682 | **Mode** | | | | | |
| **Std Dev** | 3.0166 | 3.534 | 2.1119 | 2.012 | 0.5396 | **Std Dev** | | | | | |
| **Alpha (α)** | 33.145 | 6.148 | NA | NA | 588.44 | **Alpha (α)** | | | | | |
| **Beta (β)** | 0.5240 | 20.077 | NA | NA | 0.0222 | **Beta (β)** | | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 12.721 | 12.3843 | 13.0467 | 13.372 | 12.2157 | **5%** | NA | | | | |
| **10%** | 13.631 | 13.9227 | 13.6739 | 13.977 | 12.4038 | **10%** | | | | | |
| **25%** | 15.249 | 16.394 | 14.79 | 15.050 | 12.7226 | **25%** | | | | | |
| **50%** | 17.193 | 18.9151 | 16.1371 | 16.338 | 13.083 | **50%** | | | | | |
| **75%** | 19.296 | 21.1727 | 17.607 | 17.737 | 13.4503 | **75%** | | | | | |
| **90%** | 21.328 | 22.9943 | 19.0441 | 19.098 | 13.7866 | **90%** | | | | | |
| **95%** | 22.609 | 24 | 19.9596 | 19.962 | 13.9906 | **95%** | | | | | |

# Foam and Fabric Combinations – Superior Domestic Foams

| $CO_2$ Yield (kg/kg) | | | | | | CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Triangle | Gamma | Weibull | Triangle | Lognorm | **Distrib.** | Lognorm | Lognorm | Triangle | Triangle | Weibull |
| **No. Tests** | 4 | 4 | 4 | 4 | 2 | **No. Tests** | 4 | 4 | 4 | 4 | 2 |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 | **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | 2.4276 | +Inf | +Inf | 2.3807 | +Inf | **Max** | +Inf | +Inf | 0.0759 | 0.0592 | +Inf |
| **Mean** | 1.5306 | 1.1138 | 1.8279 | 1.5871 | 1.9685 | **Mean** | 0.0191 | 0.00802 | 0.0261 | 0.0205 | 0.0554 |
| **Mode** | 2.1642 | 0.9613 | 1.9111 | 2.3807 | 1.9487 | **Mode** | 0.00435 | 0.00419 | 0.00233 | 0.00233 | 0.0574 |
| **Std Dev** | 0.5438 | 0.4122 | 0.3572 | 0.5611 | 0.1621 | **Std Dev** | 0.0247 | 0.0059 | 0.0176 | 0.0137 | 0.00592 |
| **Alpha (α)** | NA | 7.3024 | 5.945 | NA | NA | **Alpha (α)** | NA | NA | NA | NA | 11.319 |
| **Beta (β)** | NA | 0.1525 | 1.971 | NA | NA | **Beta (β)** | NA | NA | NA | NA | 0.0579 |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 0.513 | 0.5329 | 1.196 | 0.5323 | 1.7138 | **5%** | 0.00228 | 0.00219 | 0.00307 | 0.00265 | 0.045 |
| **10%** | 0.725 | 0.6289 | 1.350 | 0.7528 | 1.7657 | **10%** | 0.00326 | 0.00278 | 0.00501 | 0.00415 | 0.048 |
| **25%** | 1.146 | 0.8154 | 1.599 | 1.1904 | 1.8561 | **25%** | 0.00596 | 0.00414 | 0.0112 | 0.00895 | 0.052 |
| **50%** | 1.621 | 1.0634 | 1.853 | 1.6834 | 1.9619 | **50%** | 0.0116 | 0.00646 | 0.0231 | 0.0182 | 0.056 |
| **75%** | 1.985 | 1.3575 | 2.083 | 2.0617 | 2.0737 | **75%** | 0.0227 | 0.0101 | 0.0385 | 0.0302 | 0.060 |
| **90%** | 2.175 | 1.6639 | 2.268 | 2.2585 | 2.1798 | **90%** | 0.0415 | 0.015 | 0.0523 | 0.0409 | 0.062 |
| **95%** | 2.249 | 1.8669 | 2.371 | 2.3204 | 2.2459 | **95%** | 0.0596 | 0.0191 | 0.0592 | 0.0462 | 0.064 |

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Weibull | Lognorm | Gamma | Weibull | **Distrib.** | NA | | | | |
| **No. Tests** | 4 | 4 | 4 | 4 | 2 | **No. Tests** | NA | | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 | **Min** | NA | | | | |
| **Max** | +Inf | +Inf | +Inf | +Inf | +Inf | **Max** | | | | | |
| **Mean** | 15.1223 | 15.7336 | 14.5753 | 14.6945 | 14.1739 | **Mean** | | | | | |
| **Mode** | 13.8702 | 15.6244 | 13.5644 | 13.8437 | 14.6879 | **Mode** | | | | | |
| **Std Dev** | 4.3515 | 5.3984 | 3.2291 | 3.5359 | 1.4507 | **Std Dev** | | | | | |
| **Alpha (α)** | 12.077 | 3.199 | NA | 17.271 | 11.86 | **Alpha (α)** | | | | | |
| **Beta (β)** | 1.252 | 17.567 | NA | 0.851 | 14.797 | **Beta (β)** | | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 8.7436 | 6.9413 | 9.9275 | 9.4006 | 11.5193 | **5%** | NA | | | | |
| **10%** | 9.882 | 8.693 | 10.7492 | 10.3841 | 12.2401 | **10%** | | | | | |
| **25%** | 12.0058 | 11.8999 | 12.2769 | 12.1809 | 13.3219 | **25%** | | | | | |
| **50%** | 14.7071 | 15.6652 | 14.2302 | 14.4119 | 14.3471 | **50%** | | | | | |
| **75%** | 17.7871 | 19.4555 | 16.4943 | 16.9004 | 15.2106 | **75%** | | | | | |
| **90%** | 20.8979 | 22.7997 | 18.8385 | 19.3688 | 15.8755 | **90%** | | | | | |
| **95%** | 22.9181 | 24.7547 | 20.3978 | 20.9526 | 16.2317 | **95%** | | | | | |

# Foam and Fabric Combinations – Public Auditorium Foams

| $CO_2$ Yield (kg/kg) | | | | | | CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Gamma | Gamma | Weibull | Lognorm | **Distrib.** | Lognorm | Lognorm | Weibull | Weibull | Lognorm |
| **No. Tests** | 4 | 4 | 4 | 4 | 1 | **No. Tests** | 4 | 4 | 4 | 4 | 1 |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 | **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | +Inf | +Inf | +Inf | **Max** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.5342 | 1.0984 | 1.8814 | 1.9576 | 1.3411 | **Mean** | 0.0177 | 0.00555 | 0.0276 | 0.0261 | 0.03996 |
| **Mode** | 1.4544 | 0.877 | 1.7646 | 2.0413 | 1.3325 | **Mode** | 0.00342 | 0.00367 | 0.00817 | 0.00476 | 0.03991 |
| **Std Dev** | 0.6119 | 0.4932 | 0.4687 | 0.4351 | 0.0881 | **Std Dev** | 0.025 | 0.00313 | 0.0223 | 0.0227 | 0.0012 |
| **Alpha (α)** | 2.705 | 4.9607 | 16.114 | 5.167 | NA | **Alpha (α)** | NA | NA | 1.250 | 1.153 | NA |
| **Beta (β)** | 1.725 | 0.22142 | 0.117 | 2.128 | NA | **Beta (β)** | NA | NA | 0.0297 | 0.0273 | NA |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 0.575 | 0.4308 | 1.182 | 1.198 | 1.2013 | **5%** | 0.00183 | 0.00204 | 0.00275 | 0.00209 | 0.03801 |
| **10%** | 0.751 | 0.5325 | 1.311 | 1.377 | 1.2303 | **10%** | 0.00267 | 0.00247 | 0.0049 | 0.00389 | 0.03843 |
| **25%** | 1.088 | 0.7385 | 1.548 | 1.672 | 1.2803 | **25%** | 0.00505 | 0.00339 | 0.0109 | 0.0093 | 0.03914 |
| **50%** | 1.507 | 1.0255 | 1.843 | 1.982 | 1.3382 | **50%** | 0.0102 | 0.00484 | 0.0221 | 0.0199 | 0.03994 |
| **75%** | 1.947 | 1.3792 | 2.173 | 2.267 | 1.3988 | **75%** | 0.0207 | 0.00689 | 0.0385 | 0.0364 | 0.04076 |
| **90%** | 2.348 | 1.7586 | 2.501 | 2.501 | 1.4557 | **90%** | 0.0391 | 0.00948 | 0.0578 | 0.0565 | 0.04152 |
| **95%** | 2.588 | 2.0147 | 2.713 | 2.632 | 1.4908 | **95%** | 0.0572 | 0.0115 | 0.0714 | 0.0709 | 0.04197 |

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Weibull | Lognorm | Weibull | Gamma | **Distrib.** | NA | | | | |
| **No. Tests** | 4 | 4 | 4 | 4 | 1 | **No. Tests** | NA | | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 | **Min** | NA | | | | |
| **Max** | +Inf | +Inf | +Inf | +Inf | +Inf | **Max** | | | | | |
| **Mean** | 15.2627 | 15.0495 | 15.4361 | 16.1119 | 10.1741 | **Mean** | | | | | |
| **Mode** | 15.8216 | 15.5785 | 14.1515 | 16.8099 | 10.118 | **Mode** | | | | | |
| **Std Dev** | 3.8295 | 3.8541 | 3.7697 | 3.5185 | 0.7555 | **Std Dev** | | | | | |
| **Alpha (α)** | 4.524 | 4.4235 | NA | 5.268 | 181.37 | **Alpha (α)** | | | | | |
| **Beta (β)** | 16.72 | 16.508 | NA | 17.495 | 0.0561 | **Beta (β)** | | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 8.672 | 8.4348 | 10.093 | 9.9552 | 8.964 | **5%** | NA | | | | |
| **10%** | 10.167 | 9.9254 | 11.016 | 11.4129 | 9.219 | **10%** | | | | | |
| **25%** | 12.695 | 12.4556 | 12.749 | 13.8104 | 9.655 | **25%** | | | | | |
| **50%** | 15.419 | 15.1951 | 14.996 | 16.3194 | 10.155 | **50%** | | | | | |
| **75%** | 17.971 | 17.7728 | 17.639 | 18.6143 | 10.673 | **75%** | | | | | |
| **90%** | 20.104 | 19.933 | 20.414 | 20.4964 | 11.154 | **90%** | | | | | |
| **95%** | 21.308 | 21.1548 | 22.279 | 21.5463 | 11.448 | **95%** | | | | | |

# Foam and Fabric Combinations – Polypropylene Fabrics

| $CO_2$ Yield (kg/kg) | | | | | | CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Gamma | Triangle | Weibull | Gamma | **Distrib.** | Lognorm | Lognorm | Triangle | Triangle | Gamma |
| **No. Tests** | 5 | 5 | 5 | 5 | 4 | **No. Tests** | 5 | 5 | 5 | 5 | 4 |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 | **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | 2.8273 | +Inf | +Inf | **Max** | +Inf | +Inf | 0.0837 | 0.0803 | +Inf |
| **Mean** | 1.6421 | 1.2448 | 1.9593 | 1.9595 | 1.7165 | **Mean** | 0.0232 | 0.00699 | 0.0301 | 0.0289 | 0.0501 |
| **Mode** | 1.6727 | 1.1236 | 2.046 | 2.0489 | 1.6535 | **Mode** | 0.00509 | 0.00435 | 0.00651 | 0.00636 | 0.0485 |
| **Std Dev** | 0.4908 | 0.3884 | 0.3733 | 0.3814 | 0.3288 | **Std Dev** | 0.0307 | 0.00427 | 0.019 | 0.0182 | 0.00897 |
| **Alpha (α)** | 3.729 | 10.274 | NA | 5.971 | 27.258 | **Alpha (α)** | NA | NA | NA | NA | 31.23 |
| **Beta (β)** | 1.819 | 0.12116 | NA | 2.113 | 0.0630 | **Beta (β)** | NA | NA | NA | NA | 0.00161 |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 0.820 | 0.6819 | 1.313 | 1.2847 | 1.2138 | **5%** | 0.003 | 0.00237 | 0.00522 | 0.005 | 0.036 |
| **10%** | 0.995 | 0.7802 | 1.440 | 1.4493 | 1.3109 | **10%** | 0.004 | 0.0029 | 0.00744 | 0.007 | 0.039 |
| **25%** | 1.302 | 0.9657 | 1.694 | 1.7148 | 1.4848 | **25%** | 0.007 | 0.00409 | 0.0141 | 0.014 | 0.044 |
| **50%** | 1.649 | 1.2046 | 1.979 | 1.987 | 1.6956 | **50%** | 0.014 | 0.00597 | 0.0269 | 0.026 | 0.050 |
| **75%** | 1.985 | 1.4803 | 2.231 | 2.2316 | 1.9254 | **75%** | 0.028 | 0.00873 | 0.0435 | 0.042 | 0.056 |
| **90%** | 2.275 | 1.7612 | 2.450 | 2.4295 | 2.149 | **90%** | 0.051 | 0.0123 | 0.0583 | 0.056 | 0.062 |
| **95%** | 2.441 | 1.9447 | 2.561 | 2.539 | 2.2907 | **95%** | 0.073 | 0.0151 | 0.0657 | 0.063 | 0.066 |

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Weibull | Lognorm | Lognorm | Weibull | **Distrib.** | NA | | | | |
| **No. Tests** | 5 | 5 | 5 | 5 | 4 | **No. Tests** | NA | | | | |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 | **Min** | NA | | | | |
| **Max** | +Inf | +Inf | +Inf | +Inf | +Inf | **Max** | | | | | |
| **Mean** | 16.9535 | 18.4233 | 16.0086 | 17.0263 | 12.6188 | **Mean** | | | | | |
| **Mode** | 17.5816 | 19.1414 | 14.8557 | 16.1745 | 13.1991 | **Mode** | | | | | |
| **Std Dev** | 4.2266 | 4.4504 | 3.6185 | 3.1765 | 2.2769 | **Std Dev** | | | | | |
| **Alpha (α)** | 4.556 | 4.7168 | NA | NA | 6.482 | **Alpha (α)** | | | | | |
| **Beta (β)** | 18.564 | 20.13 | NA | NA | 13.545 | **Beta (β)** | | | | | |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 9.6729 | 10.726 | 10.816 | 12.3468 | 8.5657 | **5%** | NA | | | | |
| **10%** | 11.3285 | 12.4943 | 11.730 | 13.2051 | 9.5718 | **10%** | | | | | |
| **25%** | 14.1228 | 15.4596 | 13.432 | 14.7743 | 11.1762 | **25%** | | | | | |
| **50%** | 17.1295 | 18.628 | 15.615 | 16.7375 | 12.8001 | **50%** | | | | | |
| **75%** | 19.9441 | 21.5768 | 18.152 | 18.9615 | 14.2448 | **75%** | | | | | |
| **90%** | 22.2937 | 24.0273 | 20.786 | 21.2148 | 15.4046 | **90%** | | | | | |
| **95%** | 23.6192 | 25.4059 | 22.542 | 22.6894 | 16.0429 | **95%** | | | | | |

# Foam and Fabric Combinations – Wool Fabrics

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Gamma | Weibull | NA | |
| **No. Tests** | 5 | 5 | 5 | NA | |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | NA | |
| **Max** | +Inf | +Inf | +Inf | | |
| **Mean** | 1.4107 | 1.081 | 1.7803 | | |
| **Mode** | 1.3366 | 0.8648 | 1.8543 | | |
| **Std Dev** | 0.5633 | 0.4834 | 0.4084 | | |
| **Alpha (α)** | 2.701 | 5.0008 | 4.991 | | |
| **Beta (β)** | 1.586 | 0.21617 | 1.939 | | |
| **Percentile** | | | | | |
| **5%** | 0.5612 | 0.426 | 1.2352 | NA | |
| **10%** | 0.6996 | 0.526 | 1.3693 | | |
| **25%** | 0.9821 | 0.7283 | 1.6152 | | |
| **50%** | 1.3788 | 1.0099 | 1.9216 | | |
| **75%** | 1.871 | 1.3565 | 2.2646 | | |
| **90%** | 2.4017 | 1.7282 | 2.6058 | | |
| **95%** | 2.761 | 1.9789 | 2.8252 | | |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Lognorm | Lognorm | NA | |
| **No. Tests** | 5 | 5 | 5 | NA | |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | NA | |
| **Max** | +Inf | +Inf | +Inf | | |
| **Mean** | 0.0123 | 0.00599 | 0.0215 | | |
| **Mode** | 0.00345 | 0.00378 | 0.00497 | | |
| **Std Dev** | 0.0141 | 0.00359 | 0.0276 | | |
| **Alpha (α)** | NA | NA | NA | | |
| **Beta (β)** | NA | NA | NA | | |
| **Percentile** | | | | | |
| **5%** | 0.00177 | 0.00206 | 0.003 | NA | |
| **10%** | 0.00247 | 0.00253 | 0.004 | | |
| **25%** | 0.00432 | 0.00353 | 0.007 | | |
| **50%** | 0.00803 | 0.00514 | 0.013 | | |
| **75%** | 0.0149 | 0.00746 | 0.026 | | |
| **90%** | 0.0261 | 0.0104 | 0.047 | | |
| **95%** | 0.0365 | 0.0128 | 0.067 | | |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Weibull | Lognorm | NA | |
| **No. Tests** | 5 | 5 | 5 | NA | |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | NA | |
| **Max** | +Inf | +Inf | +Inf | | |
| **Mean** | 14.0262 | 13.8605 | 14.2165 | | |
| **Mode** | 14.5835 | 14.3283 | 13.4191 | | |
| **Std Dev** | 3.3417 | 3.6135 | 2.8159 | | |
| **Alpha (α)** | 4.789 | 4.3373 | NA | | |
| **Beta (β)** | 15.314 | 15.221 | NA | | |
| **Percentile** | | | | | |
| **5%** | 8.237 | 7.6742 | 10.0996 | NA | |
| **10%** | 9.573 | 9.0596 | 10.8456 | | |
| **25%** | 11.806 | 11.4205 | 12.2173 | | |
| **50%** | 14.186 | 13.9875 | 13.9456 | | |
| **75%** | 16.395 | 16.4113 | 15.9185 | | |
| **90%** | 18.228 | 18.448 | 17.9317 | | |
| **95%** | 19.258 | 19.6019 | 19.2563 | | |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min** | NA | | | | |
| **Max** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Foam and Fabric Combinations – All Tests

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Gamma | Weibull | Weibull | Gamma |
| **No. Tests** | 10 | 10 | 10 | 5 | 4 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.5342 | 1.1581 | 1.8536 | 1.8758 | 1.7165 |
| **Mode** | 1.5162 | 0.9765 | 1.9347 | 1.9581 | 1.6535 |
| **Std Dev** | 0.537 | 0.4586 | 0.3989 | 0.4021 | 0.3288 |
| **Alpha (α)** | 3.129 | 6.3767 | 5.353 | 5.376 | 27.258 |
| **Beta (β)** | 1.715 | 0.18161 | 2.011 | 1.035 | 0.0630 |
| **Percentile** | | | | | |
| **5%** | 0.6636 | 0.52 | 1.155 | 1.171 | 1.2138 |
| **10%** | 0.8353 | 0.6228 | 1.321 | 1.339 | 1.3109 |
| **25%** | 1.1515 | 0.8251 | 1.593 | 1.614 | 1.4848 |
| **50%** | 1.5252 | 1.0981 | 1.878 | 1.900 | 1.6956 |
| **75%** | 1.9035 | 1.426 | 2.137 | 2.162 | 1.9254 |
| **90%** | 2.2386 | 1.7708 | 2.350 | 2.376 | 2.149 |
| **95%** | 2.435 | 2.0008 | 2.468 | 2.495 | 2.2907 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Lognorm | Triangle | Gamma | Gamma |
| **No. Tests** | 10 | 10 | 10 | 5 | 4 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | 0.079 | +Inf | +Inf |
| **Mean** | 0.0179 | 0.00646 | 0.0273 | 0.0239 | 0.0501 |
| **Mode** | 0.00394 | 0.00401 | 0.0029 | 0.00777 | 0.0485 |
| **Std Dev** | 0.0237 | 0.00394 | 0.0183 | 0.0196 | 0.00897 |
| **Alpha (α)** | NA | NA | NA | 1.482 | 31.23 |
| **Beta (β)** | NA | NA | NA | 0.0161 | 0.00161 |
| **Percentile** | | | | | |
| **5%** | 0.00207 | 0.00218 | 0.00343 | 0.00275 | 0.036 |
| **10%** | 0.00298 | 0.00268 | 0.00544 | 0.00458 | 0.039 |
| **25%** | 0.00549 | 0.00377 | 0.0119 | 0.00957 | 0.044 |
| **50%** | 0.0108 | 0.00551 | 0.0242 | 0.0188 | 0.050 |
| **75%** | 0.0213 | 0.00806 | 0.0402 | 0.0327 | 0.056 |
| **90%** | 0.0393 | 0.0113 | 0.0545 | 0.0499 | 0.062 |
| **95%** | 0.0566 | 0.0139 | 0.0617 | 0.0625 | 0.066 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Weibull | Lognorm | Lognorm | Weibull |
| **No. Tests** | 10 | 10 | 10 | 5 | 4 |
| **Parameter** | | | | | |
| **Min** | 0 | 0 | 0 | 0 | 0 |
| **Max** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 15.6115 | 15.9995 | 15.2811 | 15.709 | 12.6188 |
| **Mode** | 14.5489 | 16.3381 | 14.2128 | 14.6944 | 13.1991 |
| **Std Dev** | 4.073 | 4.6963 | 3.3999 | 3.3515 | 2.2769 |
| **Alpha (α)** | 16.69 | 3.8046 | NA | NA | 6.482 |
| **Beta (β)** | 1.063 | 17.702 | NA | NA | 13.545 |
| **Percentile** | | | | | |
| **5%** | 9.568 | 8.109 | 10.3907 | 10.859 | 8.5657 |
| **10%** | 10.6718 | 9.7979 | 11.2545 | 11.724 | 9.5718 |
| **25%** | 12.7064 | 12.7583 | 12.861 | 13.326 | 11.1762 |
| **50%** | 15.2587 | 16.0758 | 14.9164 | 15.363 | 12.8001 |
| **75%** | 18.1326 | 19.2884 | 17.3002 | 17.713 | 14.2448 |
| **90%** | 21.0055 | 22.0401 | 19.7698 | 20.133 | 15.4046 |
| **95%** | 22.8586 | 23.6186 | 21.4133 | 21.737 | 16.0429 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min** | NA | | | | |
| **Max** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Foam and Fabric Combinations – All Tests

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Triangle | Gamma | Lognorm | Gamma |
| **No. Tests** | 8 | 8 | 8 | 8 | 8 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | 1.9623 | +Inf | +Inf | +Inf |
| **Mean** | 1.4078 | 1.1745 | 1.4035 | 1.425 | 1.3918 |
| **Mode** | 1.3012 | 1.5612 | 1.2563 | 1.3271 | 1.202 |
| **Std Dev** | 0.3873 | 0.4232 | 0.4545 | 0.314 | 0.514 |
| **Alpha (α)** | 13.211 | NA | 9.5373 | NA | 7.3316 |
| **Beta (β)** | 0.1066 | NA | 0.1472 | NA | 0.1898 |
| **Percentile** | | | | | |
| **5%** | 0.8367 | 0.3914 | 0.7484 | 0.9727 | 0.667 |
| **10%** | 0.9398 | 0.5535 | 0.8616 | 1.0527 | 0.7869 |
| **25%** | 1.1309 | 0.8752 | 1.0763 | 1.2015 | 1.0197 |
| **50%** | 1.3724 | 1.2377 | 1.3547 | 1.3916 | 1.3291 |
| **75%** | 1.6462 | 1.5158 | 1.6776 | 1.6117 | 1.6958 |
| **90%** | 1.9213 | 1.6818 | 2.0083 | 1.8395 | 2.0777 |
| **95%** | 2.0994 | 1.7639 | 2.2249 | 1.9909 | 2.3308 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Gamma | Weibull | Triangle | Gamma |
| **No. Tests** | 8 | 8 | 8 | 8 | 8 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | 0.0551 | +Inf |
| **Mean** | 0.0265 | 0.00528 | 0.0302 | 0.0204 | 0.0361 |
| **Mode** | 0.0168 | 0.00429 | 0.0266 | 0.00603 | 0.0324 |
| **Std Dev** | 0.0165 | 0.00228 | 0.014 | 0.0123 | 0.0116 |
| **Alpha (α)** | 1.6471 | 5.3677 | 2.2928 | NA | NA |
| **Beta (β)** | 0.02963 | 0.00098 | 0.03410 | NA | NA |
| **Percentile** | | | | | |
| **5%** | 0.00488 | 0.00217 | 0.00934 | 0.00408 | 0.0194 |
| **10%** | 0.00756 | 0.00265 | 0.0128 | 0.00576 | 0.0223 |
| **25%** | 0.0139 | 0.00362 | 0.0198 | 0.0101 | 0.0278 |
| **50%** | 0.0237 | 0.00495 | 0.0291 | 0.0183 | 0.0349 |
| **75%** | 0.0361 | 0.00658 | 0.0393 | 0.0291 | 0.0431 |
| **90%** | 0.0492 | 0.00832 | 0.0491 | 0.0386 | 0.0515 |
| **95%** | 0.0577 | 0.00949 | 0.055 | 0.0434 | 0.057 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Weibull | Gamma | Gamma | Weibull |
| **No. Tests** | 8 | 8 | 8 | 8 | 8 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 15.0626 | 16.4923 | 14.5156 | 14.218 | 14.6353 |
| **Mode** | 14.0778 | 17.246 | 13.0715 | 13.5495 | 14.6179 |
| **Std Dev** | 3.8514 | 2.7597 | 4.5784 | 3.0831 | 4.8939 |
| **Alpha (α)** | 15.295 | 7.031 | 10.052 | 21.266 | 3.2919 |
| **Beta (β)** | 0.9848 | 17.626 | 1.444 | 0.6686 | 16.318 |
| **Percentile** | | | | | |
| **5%** | 9.3346 | 11.5532 | 7.8898 | 9.5542 | 6.6191 |
| **10%** | 10.3854 | 12.7987 | 9.0434 | 10.4375 | 8.237 |
| **25%** | 12.3179 | 14.7642 | 11.2234 | 12.0353 | 11.176 |
| **50%** | 14.7356 | 16.7312 | 14.0371 | 13.9958 | 14.5983 |
| **75%** | 17.4514 | 18.4647 | 17.2874 | 16.1588 | 18.0197 |
| **90%** | 20.1609 | 19.8464 | 20.6048 | 18.2846 | 21.0227 |
| **95%** | 21.9062 | 20.6033 | 22.7741 | 19.6401 | 22.7723 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| | | | | | |
| **Min.** | NA | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Foam and Fabric Combinations – Aviation Foams

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Weibull | Lognorm | Lognorm | Gamma |
| **No. Tests** | 15 | 15 | 14 | 14 | 6 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.8303 | 1.5331 | 1.9767 | 2.15 | 1.8738 |
| **Mode** | 1.7149 | 1.5845 | 1.867 | 2.0553 | 1.8109 |
| **Std Dev** | 0.4597 | 0.401 | 0.389 | 0.3753 | 0.3434 |
| **Alpha (α)** | 15.85 | 4.324 | NA | NA | 29.769 |
| **Beta (β)** | 0.115 | 1.684 | NA | NA | 0.062947 |
| **Percentile** | | | | | |
| **5%** | 1.1452 | 0.8472 | 1.407 | 1.5927 | 1.3469 |
| **10%** | 1.2714 | 1.0007 | 1.5104 | 1.6962 | 1.4494 |
| **25%** | 1.5029 | 1.2624 | 1.7003 | 1.8844 | 1.6322 |
| **50%** | 1.792 | 1.5471 | 1.9394 | 2.118 | 1.8529 |
| **75%** | 2.116 | 1.816 | 2.2122 | 2.3805 | 2.0927 |
| **90%** | 2.4386 | 2.0421 | 2.4903 | 2.6445 | 2.3253 |
| **95%** | 2.6463 | 2.1703 | 2.6733 | 2.8164 | 2.4722 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Gamma | Weibull | Gamma | Triangle |
| **No. Tests** | 15 | 15 | 14 | 14 | 6 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | 0.0364 |
| **Mean** | 0.0186 | 0.00912 | 0.0232 | 0.0205 | 0.0214 |
| **Mode** | 0.0119 | 0.00757 | 0.0211 | 0.0168 | 0.0279 |
| **Std Dev** | 0.0111 | 0.00376 | 0.0101 | 0.00862 | 0.00777 |
| **Alpha (α)** | 2.794 | 5.879 | 2.452 | 5.6339 | NA |
| **Beta (β)** | 0.00665 | 0.00155 | 0.0262 | 0.003631 | NA |
| **Percentile** | | | | | |
| **5%** | 0.00475 | 0.00393 | 0.00779 | 0.00862 | 0.00712 |
| **10%** | 0.0065 | 0.00475 | 0.0105 | 0.0105 | 0.0101 |
| **25%** | 0.0104 | 0.00639 | 0.0157 | 0.0142 | 0.0159 |
| **50%** | 0.0164 | 0.00861 | 0.0225 | 0.0193 | 0.0225 |
| **75%** | 0.0244 | 0.0113 | 0.0299 | 0.0254 | 0.0276 |
| **90%** | 0.0335 | 0.0142 | 0.0368 | 0.032 | 0.0308 |
| **95%** | 0.0398 | 0.0161 | 0.0409 | 0.0364 | 0.0324 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Gamma | Lognorm | Lognorm | Gamma |
| **No. Tests** | 15 | 15 | 14 | 14 | 6 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 17.583 | 15.416 | 18.599 | 22.2661 | 16.4644 |
| **Mode** | 15.777 | 14.308 | 17.106 | 20.8959 | 15.9824 |
| **Std Dev** | 4.813 | 4.132 | 4.456 | 4.6307 | 2.817 |
| **Alpha (α)** | NA | 13.918 | NA | NA | 34.16 |
| **Beta (β)** | NA | 1.1077 | NA | NA | 0.48198 |
| **Percentile** | | | | | |
| **5%** | 10.8994 | 9.3041 | 12.264 | 15.5402 | 12.1205 |
| **10%** | 12.0175 | 10.4137 | 13.363 | 16.7465 | 12.9731 |
| **25%** | 14.1474 | 12.4653 | 15.4235 | 18.9746 | 14.4871 |
| **50%** | 16.9594 | 15.0484 | 18.0876 | 21.7997 | 16.304 |
| **75%** | 20.3304 | 17.9666 | 21.2118 | 25.0453 | 18.2669 |
| **90%** | 23.9337 | 20.8919 | 24.4826 | 28.3776 | 20.1619 |
| **95%** | 26.3887 | 22.7823 | 26.6765 | 30.5804 | 21.3553 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min.** | NA | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Foam and Fabric Combinations – Domestic Furniture Foams

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Weibull | Gamma | Gamma | Weibull |
| **No. Tests** | 21 | 21 | 21 | 21 | 12 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.8173 | 1.6024 | 1.9052 | 2.1971 | 1.7089 |
| **Mode** | 1.6922 | 1.6689 | 1.7605 | 2.0606 | 1.7826 |
| **Std Dev** | 0.4768 | 0.368 | 0.525 | 0.5476 | 0.3754 |
| **Alpha (α)** | 14.528 | 4.9856 | 13.167 | 16.099 | 5.2333 |
| **Beta (β)** | 0.1251 | 1.7455 | 0.1447 | 0.1365 | 1.8563 |
| **Percentile** | | | | | |
| **5%** | 1.1103 | 0.962 | 1.1313 | 1.3803 | 1.0524 |
| **10%** | 1.2393 | 1.1115 | 1.2709 | 1.531 | 1.2075 |
| **25%** | 1.4771 | 1.3596 | 1.5299 | 1.8073 | 1.4631 |
| **50%** | 1.7758 | 1.6218 | 1.8572 | 2.1518 | 1.7308 |
| **75%** | 2.1122 | 1.8637 | 2.2283 | 2.5376 | 1.9759 |
| **90%** | 2.4488 | 2.0634 | 2.6014 | 2.9215 | 2.1771 |
| **95%** | 2.666 | 2.1752 | 2.843 | 3.1685 | 2.2893 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Gamma | Weibull | Triangle | Gamma |
| **No. Tests** | 21 | 21 | 21 | 21 | 12 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | 0.0612 | +Inf |
| **Mean** | 0.0205 | 0.00513 | 0.0267 | 0.0228 | 0.03 |
| **Mode** | 0.0056 | 0.00444 | 0.0213 | 0.0073 | 0.0227 |
| **Std Dev** | 0.0241 | 0.00188 | 0.014 | 0.0136 | 0.0148 |
| **Alpha (α)** | NA | 7.414 | 1.999 | NA | 4.1016 |
| **Beta (β)** | NA | 0.000692 | 0.03014 | NA | 0.00732 |
| **Percentile** | | | | | |
| **5%** | 0.00288 | 0.00247 | 0.00682 | 0.00473 | 0.00959 |
| **10%** | 0.00404 | 0.00291 | 0.00978 | 0.00668 | 0.013 |
| **25%** | 0.0071 | 0.00376 | 0.0162 | 0.0115 | 0.02 |
| **50%** | 0.0133 | 0.0049 | 0.0251 | 0.0206 | 0.029 |
| **75%** | 0.0249 | 0.00624 | 0.0355 | 0.0325 | 0.0389 |
| **90%** | 0.0438 | 0.00764 | 0.0457 | 0.043 | 0.0483 |
| **95%** | 0.0615 | 0.00857 | 0.0522 | 0.0483 | 0.054 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Gamma | Weibull | Weibull | Weibull |
| **No. Tests** | 21 | 21 | 21 | 21 | 12 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 17.3127 | 17.4023 | 16.9591 | 21.758 | 13.770 |
| **Mode** | 15.4951 | 16.3774 | 16.439 | 22.356 | 14.101 |
| **Std Dev** | 5.6097 | 4.2232 | 6.3534 | 6.061 | 3.952 |
| **Alpha (α)** | 9.525 | 16.98 | 2.9002 | 4.031 | 3.900 |
| **Beta (β)** | 1.818 | 1.0249 | 19.019 | 23.994 | 15.213 |
| **Percentile** | | | | | |
| **5%** | 9.2275 | 11.0851 | 6.83 | 11.4847 | 7.104 |
| **10%** | 10.6242 | 12.2567 | 8.754 | 13.7299 | 8.5439 |
| **25%** | 13.2743 | 14.3991 | 12.3772 | 17.6149 | 11.0535 |
| **50%** | 16.7108 | 17.0619 | 16.7612 | 21.9087 | 13.849 |
| **75%** | 20.6966 | 20.035 | 21.2863 | 26.019 | 16.5424 |
| **90%** | 24.7778 | 22.9863 | 25.3559 | 29.5089 | 18.8406 |
| **95%** | 27.4524 | 24.8811 | 27.7642 | 31.4994 | 20.1557 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min.** | NA | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Foam and Fabric Combinations – Public Auditorium Foams

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Lognorm | Lognorm | Gamma | Lognorm |
| **No. Tests** | 2 | 2 | 2 | 2 | 2 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.8801 | 1.6304 | 1.9326 | 2.0392 | 1.9041 |
| **Mode** | 1.7977 | 1.5729 | 1.8588 | 2.0361 | 1.8177 |
| **Std Dev** | 0.3274 | 0.2536 | 0.3134 | 0.0797 | 0.3376 |
| **Alpha (α)** | NA | NA | NA | 654.2 | NA |
| **Beta (β)** | NA | NA | NA | 0.00312 | NA |
| **Percentile** | | | | | |
| **5%** | 1.3939 | 1.2493 | 1.4636 | 1.9099 | 1.4037 |
| **10%** | 1.4842 | 1.3215 | 1.5518 | 1.9378 | 1.4964 |
| **25%** | 1.6484 | 1.4515 | 1.7113 | 1.9849 | 1.665 |
| **50%** | 1.8522 | 1.611 | 1.9077 | 2.0382 | 1.8749 |
| **75%** | 2.0812 | 1.788 | 2.1267 | 2.0924 | 2.1111 |
| **90%** | 2.3114 | 1.964 | 2.3453 | 2.142 | 2.3491 |
| **95%** | 2.4612 | 2.0774 | 2.4867 | 2.1721 | 2.5041 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Triangle | Lognorm | Triangle | Lognorm | Triangle |
| **No. Tests** | 2 | 2 | 2 | 2 | 2 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | 0.0584 | +Inf | 0.0586 | +Inf | 0.0584 |
| **Mean** | 0.0211 | 0.00485 | 0.024 | 0.0167 | 0.0266 |
| **Mode** | 0.00482 | 0.00458 | 0.0133 | 0.0111 | 0.0213 |
| **Std Dev** | 0.0132 | 0.000967 | 0.0126 | 0.00942 | 0.0121 |
| **Alpha (α)** | NA | NA | NA | NA | NA |
| **Beta (β)** | NA | NA | NA | NA | NA |
| **Percentile** | | | | | |
| **5%** | 0.00375 | 0.00344 | 0.00625 | 0.00615 | 0.00789 |
| **10%** | 0.00533 | 0.00369 | 0.00883 | 0.00744 | 0.0112 |
| **25%** | 0.00995 | 0.00416 | 0.014 | 0.0102 | 0.0177 |
| **50%** | 0.0188 | 0.00476 | 0.0222 | 0.0146 | 0.0255 |
| **75%** | 0.0304 | 0.00544 | 0.0329 | 0.0208 | 0.0351 |
| **90%** | 0.0407 | 0.00613 | 0.0423 | 0.0286 | 0.0437 |
| **95%** | 0.0459 | 0.00658 | 0.0471 | 0.0346 | 0.048 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Lognorm | Lognorm | Lognorm | Lognorm |
| **No. Tests** | 2 | 2 | 2 | 2 | 2 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 16.999 | 16.5288 | 17.0908 | 19.7937 | 16.3745 |
| **Mode** | 16.0683 | 15.2465 | 16.249 | 19.4013 | 15.6347 |
| **Std Dev** | 3.3247 | 3.8873 | 3.1629 | 2.2946 | 2.8971 |
| **Alpha (α)** | NA | NA | NA | NA | NA |
| **Beta (β)** | NA | NA | NA | NA | NA |
| **Percentile** | | | | | |
| **5%** | 12.1302 | 10.985 | 12.4269 | 16.2589 | 12.0798 |
| **10%** | 13.0148 | 11.9512 | 13.2836 | 16.9559 | 12.8754 |
| **25%** | 14.6392 | 13.7589 | 14.849 | 18.1879 | 14.3235 |
| **50%** | 16.6829 | 16.0898 | 16.8055 | 19.662 | 16.1241 |
| **75%** | 19.0119 | 18.8156 | 19.0198 | 21.2556 | 18.1511 |
| **90%** | 21.3849 | 21.6616 | 21.2611 | 22.7999 | 20.1925 |
| **95%** | 22.9444 | 23.5667 | 22.7268 | 23.7774 | 21.5224 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min.** | NA | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Foam and Fabric Combinations – Polypropylene Fabrics

| $CO_2$ Yield (kg/kg) | | | | | | CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Gamma | Gamma | Lognorm | Weibull | **Distrib.** | Gamma | Lognorm | Gamma | Lognorm | Gamma |
| **No. Tests** | 18 | 18 | 18 | 18 | 11 | **No. Tests** | 18 | 18 | 18 | 18 | 11 |
| **Parameter** | | | | | | **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 | **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf | **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.8467 | 1.5372 | 1.9472 | 2.2187 | 1.81 | **Mean** | 0.0198 | 0.00776 | 0.0238 | 0.0216 | 0.0248 |
| **Mode** | 1.7312 | 1.4674 | 1.8375 | 2.1111 | 1.891 | **Mode** | 0.0115 | 0.00554 | 0.0176 | 0.015 | 0.0183 |
| **Std Dev** | 0.4618 | 0.3276 | 0.4622 | 0.4072 | 0.3733 | **Std Dev** | 0.0128 | 0.00389 | 0.0121 | 0.0113 | 0.0127 |
| **Alpha (α)** | 15.992 | 22.023 | 17.745 | NA | 5.607 | **Alpha (α)** | 2.380 | NA | 3.883 | NA | 3.802 |
| **Beta (β)** | 0.115 | 0.0698 | 0.110 | NA | 1.958 | **Beta (β)** | 0.00832 | NA | 0.00612 | NA | 0.00652 |
| **Percentile** | | | | | | **Percentile** | | | | | |
| **5%** | 1.1582 | 1.0409 | 1.2542 | 1.6176 | 1.1531 | **5%** | 0.00431 | 0.00318 | 0.00795 | 0.00852 | 0.00817 |
| **10%** | 1.2851 | 1.1352 | 1.3833 | 1.7282 | 1.311 | **10%** | 0.00613 | 0.00378 | 0.0102 | 0.0102 | 0.0105 |
| **25%** | 1.5179 | 1.3055 | 1.6188 | 1.9301 | 1.5682 | **25%** | 0.0104 | 0.00504 | 0.0149 | 0.0137 | 0.0155 |
| **50%** | 1.8084 | 1.514 | 1.9108 | 2.1822 | 1.8345 | **50%** | 0.0171 | 0.00694 | 0.0218 | 0.0191 | 0.0227 |
| **75%** | 2.1338 | 1.7437 | 2.236 | 2.4673 | 2.0759 | **75%** | 0.0263 | 0.00955 | 0.0304 | 0.0266 | 0.0318 |
| **90%** | 2.4577 | 1.9691 | 2.5581 | 2.7556 | 2.2725 | **90%** | 0.037 | 0.0127 | 0.0399 | 0.0359 | 0.0418 |
| **95%** | 2.6661 | 2.1127 | 2.7647 | 2.944 | 2.3817 | **95%** | 0.0445 | 0.0151 | 0.0464 | 0.0429 | 0.0487 |

| Heat of Combustion (MJ/kg) | | | | | | Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** | **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Lognorm | Gamma | Gamma | Weibull | **Distrib.** | NA | | | | |
| **No. Tests** | 18 | 18 | 18 | 18 | 11 | **No. Tests** | NA | | | | |
| **Parameter** | | | | | | | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 | **Min.** | NA | | | | |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf | **Max.** | | | | | |
| **Mean** | 17.6978 | 16.321 | 18.1135 | 22.8823 | 15.7597 | **Mean** | | | | | |
| **Mode** | 16.3377 | 15.0567 | 16.5461 | 21.9154 | 16.4707 | **Mode** | | | | | |
| **Std Dev** | 4.9063 | 3.8354 | 5.3283 | 4.7037 | 3.186 | **Std Dev** | | | | | |
| **Alpha (α)** | 13.01 | NA | 11.557 | 23.666 | 5.730 | **Alpha (α)** | | | | | |
| **Beta (β)** | 1.360 | NA | 1.567 | 0.967 | 17.031 | **Beta (β)** | | | | | |
| **Percentile** | | | | | | | | | | | |
| **5%** | 10.4712 | 10.8506 | 10.3259 | 15.7327 | 10.1422 | **5%** | NA | | | | |
| **10%** | 11.7728 | 11.8042 | 11.7079 | 17.0991 | 11.4997 | **10%** | | | | | |
| **25%** | 14.1894 | 13.5882 | 14.2937 | 19.5591 | 13.7031 | **25%** | | | | | |
| **50%** | 17.2466 | 15.8882 | 17.5938 | 22.5608 | 15.976 | **50%** | | | | | |
| **75%** | 20.7152 | 18.5776 | 21.3679 | 25.8554 | 18.0303 | **75%** | | | | | |
| **90%** | 24.2044 | 21.3853 | 25.189 | 29.0793 | 19.6997 | **90%** | | | | | |
| **95%** | 26.4644 | 23.2646 | 27.6746 | 31.1287 | 20.6255 | **95%** | | | | | |

# Foam and Fabric Combinations – Wool Fabrics

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Gamma | Weibull | Gamma | Weibull | Weibull |
| No. Tests | 17 | 17 | 16 | 16 | 6 |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | 0 | 0 |
| Max. | +Inf | +Inf | +Inf | +Inf | +Inf |
| Mean | 1.8467 | 1.5971 | 1.9035 | 2.159 | 1.566 |
| Mode | 1.7312 | 1.6589 | 1.7466 | 2.2413 | 1.6377 |
| Std Dev | 0.4618 | 0.3876 | 0.5464 | 0.5291 | 0.2974 |
| Alpha (α) | 15.992 | 4.693 | 12.138 | 4.643 | 6.132 |
| Beta (β) | 0.115 | 1.746 | 0.157 | 2.362 | 1.686 |
| Percentile | | | | | |
| 5% | 1.1582 | 0.9271 | 1.1023 | 1.2456 | 1.0387 |
| 10% | 1.2851 | 1.0808 | 1.2454 | 1.4545 | 1.1681 |
| 25% | 1.5179 | 1.3388 | 1.5122 | 1.8058 | 1.376 |
| 50% | 1.8084 | 1.6147 | 1.8515 | 2.1823 | 1.5881 |
| 75% | 2.1338 | 1.8717 | 2.2382 | 2.5336 | 1.7782 |
| 90% | 2.4577 | 2.0855 | 2.6286 | 2.8262 | 1.9316 |
| 95% | 2.6661 | 2.2058 | 2.8821 | 2.991 | 2.0163 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Gamma | Gamma | Weibull | Triangle | Gamma |
| No. Tests | 17 | 17 | 16 | 16 | 6 |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | 0 | 0 |
| Max. | +Inf | +Inf | +Inf | 0.0601 | +Inf |
| Mean | 0.0198 | 0.00522 | 0.0268 | 0.022 | 0.0354 |
| Mode | 0.0115 | 0.00443 | 0.022 | 0.00599 | 0.0332 |
| Std Dev | 0.0128 | 0.00204 | 0.0135 | 0.0135 | 0.0088 |
| Alpha (α) | 2.380 | 6.578 | 2.077 | NA | 16.183 |
| Beta (β) | 0.00832 | 0.000794 | 0.0302 | NA | 0.00219 |
| Percentile | | | | | |
| 5% | 0.00431 | 0.00238 | 0.00723 | 0.00424 | 0.0223 |
| 10% | 0.00613 | 0.00284 | 0.0102 | 0.006 | 0.0247 |
| 25% | 0.0104 | 0.00375 | 0.0166 | 0.0107 | 0.0291 |
| 50% | 0.0171 | 0.00496 | 0.0253 | 0.0198 | 0.0347 |
| 75% | 0.0263 | 0.00642 | 0.0354 | 0.0316 | 0.0409 |
| 90% | 0.037 | 0.00795 | 0.0452 | 0.0421 | 0.047 |
| 95% | 0.0445 | 0.00896 | 0.0513 | 0.0473 | 0.051 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Gamma | Weibull | Weibull | Weibull | Weibull |
| No. Tests | 17 | 17 | 16 | 16 | 6 |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | 0 | 0 |
| Max. | +Inf | +Inf | +Inf | +Inf | +Inf |
| Mean | 17.6978 | 17.0834 | 16.9539 | 21.4609 | 11.1051 |
| Mode | 16.3377 | 17.6536 | 15.5767 | 21.9482 | 11.1898 |
| Std Dev | 4.9063 | 4.4741 | 7.2548 | 6.2253 | 3.5522 |
| Alpha (α) | 13.011 | 4.316 | 2.5 | 3.855 | 3.459 |
| Beta (β) | 1.360 | 18.766 | 19.108 | 23.727 | 12.35 |
| Percentile | | | | | |
| 5% | 10.4712 | 9.4288 | 5.8242 | 10.98 | 5.2325 |
| 10% | 11.7728 | 11.1403 | 7.7675 | 13.2342 | 6.4431 |
| 25% | 14.1894 | 14.0598 | 11.6086 | 17.1738 | 8.6144 |
| 50% | 17.2466 | 17.2376 | 16.5024 | 21.5745 | 11.1084 |
| 75% | 20.7152 | 20.241 | 21.7751 | 25.8246 | 13.5735 |
| 90% | 24.2044 | 22.7663 | 26.6751 | 29.4577 | 15.7183 |
| 95% | 26.4644 | 24.1978 | 29.6361 | 31.539 | 16.9609 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | NA | | | | |
| No. Tests | NA | | | | |
| | | | | | |
| Min. | NA | | | | |
| Max. | | | | | |
| Mean | | | | | |
| Mode | | | | | |
| Std Dev | | | | | |
| Alpha (α) | | | | | |
| Beta (β) | | | | | |
| | | | | | |
| 5% | NA | | | | |
| 10% | | | | | |
| 25% | | | | | |
| 50% | | | | | |
| 75% | | | | | |
| 90% | | | | | |
| 95% | | | | | |

# Foam and Fabric Combinations – All Tests

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Weibull | Gamma | Gamma | Gamma |
| **No. Tests** | 38 | 38 | 37 | 37 | 20 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.827 | 1.5794 | 1.9328 | 2.1722 | 1.794 |
| **Mode** | 1.7107 | 1.6421 | 1.8213 | 2.0673 | 1.7048 |
| **Std Dev** | 0.461 | 0.3764 | 0.4643 | 0.4774 | 0.4002 |
| **Alpha (α)** | 15.707 | 4.7879 | 17.33 | 20.702 | 20.098 |
| **Beta (β)** | 0.1163 | 1.7245 | 0.112 | 0.105 | 0.0893 |
| **Percentile** | | | | | |
| **5%** | 1.1404 | 0.9273 | 1.2376 | 1.4509 | 1.1903 |
| **10%** | 1.2667 | 1.0778 | 1.3668 | 1.5872 | 1.3041 |
| **25%** | 1.4987 | 1.3294 | 1.6028 | 1.834 | 1.5104 |
| **50%** | 1.7884 | 1.5974 | 1.8958 | 2.1373 | 1.7644 |
| **75%** | 2.1133 | 1.8462 | 2.2225 | 2.4724 | 2.0454 |
| **90%** | 2.4371 | 2.0526 | 2.5466 | 2.8021 | 2.3222 |
| **95%** | 2.6454 | 2.1686 | 2.7545 | 3.0124 | 2.499 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Lognorm | Weibull | Gamma | Gamma |
| **No. Tests** | 38 | 38 | 37 | 37 | 20 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 0.0194 | 0.00653 | 0.0254 | 0.0209 | 0.0279 |
| **Mode** | 0.00853 | 0.00466 | 0.0211 | 0.0144 | 0.0211 |
| **Std Dev** | 0.0145 | 0.00328 | 0.0127 | 0.0116 | 0.0138 |
| **Alpha (α)** | 1.786 | NA | 2.1083 | 3.233 | 4.120 |
| **Beta (β)** | 0.0109 | NA | 0.0287 | 0.00647 | 0.00678 |
| **Percentile** | | | | | |
| **5%** | 0.00296 | 0.00268 | 0.00701 | 0.00607 | 0.00973 |
| **10%** | 0.00461 | 0.00318 | 0.00986 | 0.00806 | 0.0124 |
| **25%** | 0.00875 | 0.00424 | 0.0159 | 0.0124 | 0.0179 |
| **50%** | 0.0159 | 0.00584 | 0.0241 | 0.0188 | 0.0257 |
| **75%** | 0.0263 | 0.00803 | 0.0335 | 0.0272 | 0.0356 |
| **90%** | 0.0387 | 0.0107 | 0.0426 | 0.0365 | 0.0464 |
| **95%** | 0.0477 | 0.0127 | 0.0482 | 0.0429 | 0.0537 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Gamma | Gamma | Gamma | Weibull |
| **No. Tests** | 38 | 38 | 37 | 37 | 20 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 17.3734 | 16.66 | 17.5702 | 21.9126 | 15.0218 |
| **Mode** | 15.8665 | 15.5542 | 15.6245 | 20.35 | 15.6051 |
| **Std Dev** | 5.1167 | 4.2923 | 5.8469 | 5.8516 | 3.6382 |
| **Alpha (α)** | 11.529 | 15.065 | 9.0304 | 14.023 | 4.7034 |
| **Beta (β)** | 1.507 | 1.1059 | 1.9457 | 1.5626 | 16.419 |
| **Percentile** | | | | | |
| **5%** | 9.8962 | 10.2819 | 9.1781 | 13.2539 | 8.7313 |
| **10%** | 11.2227 | 11.45 | 10.6161 | 14.8271 | 10.1753 |
| **25%** | 13.7051 | 13.6002 | 13.3562 | 17.7349 | 12.5979 |
| **50%** | 16.8738 | 16.2929 | 16.9261 | 21.394 | 15.1879 |
| **75%** | 20.4982 | 19.3203 | 21.084 | 25.5259 | 17.5995 |
| **90%** | 24.1682 | 22.3429 | 25.3555 | 29.6662 | 19.6043 |
| **95%** | 26.5558 | 24.2909 | 28.1607 | 32.341 | 20.7324 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min.** | NA | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Grouped – All Wallboard Tests

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Gamma | Weibull | Gamma | Lognorm |
| **No. Tests** | 38 | 38 | 38 | 38 | 10 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 13.3232 | 11.9227 | 14.8832 | 16.3208 | 4.3707 |
| **Mode** | 9.7191 | 9.711 | 10.8428 | 12.3937 | 4.2101 |
| **Std Dev** | 6.9295 | 5.135 | 8.4476 | 8.0057 | 0.695 |
| **Alpha (α)** | 3.6967 | 5.3909 | 1.8255 | 4.156 | NA |
| **Beta (β)** | 3.6041 | 2.2116 | 16.747 | 3.927 | NA |
| **Percentile** | | | | | |
| **5%** | 4.2999 | 4.9041 | 3.291 | 5.7233 | 3.3286 |
| **10%** | 5.5654 | 5.9947 | 4.8818 | 7.2632 | 3.5252 |
| **25%** | 8.2427 | 8.1815 | 8.4633 | 10.4613 | 3.8801 |
| **50%** | 12.143 | 11.1941 | 13.7008 | 15.0321 | 4.3165 |
| **75%** | 17.1258 | 14.8732 | 20.0283 | 20.7839 | 4.8019 |
| **90%** | 22.6137 | 18.7935 | 26.4456 | 27.0499 | 5.2854 |
| **95%** | 26.3773 | 21.4286 | 30.5463 | 31.3192 | 5.5977 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Expon | Weibull | Weibull | Weibull | Lognorm |
| **No. Tests** | 38 | 38 | 38 | 38 | 10 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 0.0398 | 0.0288 | 0.0523 | 0.0585 | 0.00430 |
| **Mode** | 0 | 0.0201 | 0 | 0 | 0.000819 |
| **Std Dev** | 0.0398 | 0.0168 | 0.0694 | 0.0669 | 0.00612 |
| **Alpha (α)** | NA | 1.7655 | 0.76361 | 0.8758 | NA |
| **Beta (β)** | 0.0398 | 0.0323 | 0.044595 | 0.0547 | NA |
| **Percentile** | | | | | |
| **5%** | 0.00204 | 0.00601 | 0.000912 | 0.00184 | 0.000439 |
| **10%** | 0.00419 | 0.00903 | 0.00234 | 0.00419 | 0.000643 |
| **25%** | 0.0114 | 0.0159 | 0.00872 | 0.0132 | 0.00122 |
| **50%** | 0.0276 | 0.0262 | 0.0276 | 0.036 | 0.00248 |
| **75%** | 0.0551 | 0.0389 | 0.0684 | 0.0794 | 0.00503 |
| **90%** | 0.0916 | 0.0518 | 0.1329 | 0.1418 | 0.00953 |
| **95%** | 0.1191 | 0.0601 | 0.1876 | 0.1915 | 0.014 |

# Grouped – All Carpet Tests

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Weibull | Gamma | Weibull | Weibull | Lognorm |
| No. Tests | 47 | 47 | 47 | 47 | 27 |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | 0 | 0 |
| Max. | +Inf | +Inf | +Inf | +Inf | +Inf |
| Mean | 1.9004 | 2.0322 | 2.0638 | 2.3156 | 1.6485 |
| Mode | 1.137 | 1.4831 | 1.4021 | 1.4093 | 1.3226 |
| Std Dev | 1.2223 | 1.0563 | 1.2323 | 1.4761 | 0.6556 |
| Alpha (α) | 1.5911 | 3.701 | 1.7263 | 1.6067 | NA |
| Beta (β) | 2.1185 | 0.549 | 2.3153 | 2.5837 | NA |
| Percentile | | | | | |
| 5% | 0.3276 | 0.6564 | 0.4144 | 0.4068 | 0.8156 |
| 10% | 0.515 | 0.8494 | 0.6287 | 0.6367 | 0.9374 |
| 25% | 0.9682 | 1.2577 | 1.125 | 1.1898 | 1.183 |
| 50% | 1.6826 | 1.8523 | 1.8724 | 2.0567 | 1.5318 |
| 75% | 2.6013 | 2.6119 | 2.7976 | 3.1662 | 1.9836 |
| 90% | 3.5784 | 3.4484 | 3.7535 | 4.342 | 2.5032 |
| 95% | 4.222 | 4.022 | 4.3716 | 5.1147 | 2.8771 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Weibull | Lognorm | Weibull | Triangle | Gamma |
| No. Tests | 44 | 44 | 44 | 44 | 27 |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | 0 | 0 |
| Max. | +Inf | +Inf | +Inf | 0.1212 | +Inf |
| Mean | 0.0683 | 0.0327 | 0.0789 | 0.0629 | 0.0991 |
| Mode | 0.0574 | 0.0234 | 0.0765 | 0.0675 | 0.096 |
| Std Dev | 0.0337 | 0.0163 | 0.0295 | 0.0248 | 0.0175 |
| Alpha (α) | 2.1374 | NA | 2.9059 | NA | 32.08 |
| Beta (β) | 0.0772 | NA | 0.0885 | NA | 0.00309 |
| Percentile | | | | | |
| 5% | 0.0192 | 0.0134 | 0.0318 | 0.0202 | 0.0722 |
| 10% | 0.0269 | 0.016 | 0.0408 | 0.0286 | 0.0774 |
| 25% | 0.0431 | 0.0213 | 0.0576 | 0.0452 | 0.0868 |
| 50% | 0.065 | 0.0292 | 0.078 | 0.064 | 0.0981 |
| 75% | 0.0899 | 0.0402 | 0.099 | 0.0809 | 0.1103 |
| 90% | 0.114 | 0.0536 | 0.1179 | 0.0957 | 0.1221 |
| 95% | 0.1289 | 0.0636 | 0.1291 | 0.1032 | 0.1295 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | Weibull | Weibull | Weibull | Weibull | Gamma |
| No. Tests | 47 | 47 | 47 | 47 | 27 |
| Parameter | | | | | |
| Min. | 0 | 0 | 0 | 0 | 0 |
| Max. | +Inf | +Inf | +Inf | +Inf | +Inf |
| Mean | 15.844 | 17.333 | 15.375 | 18.605 | 10.162 |
| Mode | 3.0223 | 1.3879 | 3.562 | 4.609 | 4.9145 |
| Std Dev | 13.700 | 16.212 | 12.930 | 15.477 | 7.3023 |
| Alpha (α) | 1.1598 | 1.0698 | 1.1939 | 1.208 | 1.9366 |
| Beta (β) | 16.689 | 17.793 | 16.323 | 19.81 | 5.2473 |
| Percentile | | | | | |
| 5% | 1.289 | 1.108 | 1.356 | 1.693 | 1.7328 |
| 10% | 2.3977 | 2.1713 | 2.479 | 3.073 | 2.6198 |
| 25% | 5.7006 | 5.553 | 5.749 | 7.060 | 4.8007 |
| 50% | 12.167 | 12.632 | 12.008 | 14.624 | 8.4764 |
| 75% | 22.118 | 24.147 | 21.459 | 25.963 | 13.710 |
| 90% | 34.256 | 38.800 | 32.824 | 39.522 | 19.914 |
| 95% | 42.981 | 49.620 | 40.918 | 49.145 | 24.351 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| Stages | All | G | TS | T | S |
| Distrib. | NA | | | | |
| No. Tests | NA | | | | |
| Parameter | | | | | |
| Min. | NA | | | | |
| Max. | | | | | |
| Mean | | | | | |
| Mode | | | | | |
| Std Dev | | | | | |
| Alpha (α) | | | | | |
| Beta (β) | | | | | |
| Percentile | | | | | |
| 5% | NA | | | | |
| 10% | | | | | |
| 25% | | | | | |
| 50% | | | | | |
| 75% | | | | | |
| 90% | | | | | |
| 95% | | | | | |

# Grouped – All Furniture Tests containing Non Fire-Retarded Polyurethane Foams

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Weibull | Weibull | Gamma | Weibull |
| **No. Tests** | 46 | 46 | 46 | 46 | 27 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.7738 | 1.5636 | 1.8749 | 2.0213 | 1.659 |
| **Mode** | 1.6068 | 1.595 | 1.8944 | 1.8541 | 1.6812 |
| **Std Dev** | 0.5442 | 0.4626 | 0.5904 | 0.5814 | 0.5133 |
| **Alpha (α)** | 10.623 | 3.7718 | 3.5193 | 12.086 | 3.589 |
| **Beta (β)** | 0.1670 | 1.7307 | 2.0831 | 0.1672 | 1.841 |
| **Percentile** | | | | | |
| **5%** | 0.983 | 0.7875 | 0.8958 | 1.169 | 0.8049 |
| **10%** | 1.1218 | 0.953 | 1.0991 | 1.3211 | 0.9836 |
| **25%** | 1.3829 | 1.2439 | 1.4621 | 1.6049 | 1.3013 |
| **50%** | 1.7184 | 1.5705 | 1.8771 | 1.9659 | 1.6626 |
| **75%** | 2.1044 | 1.8873 | 2.2857 | 2.3774 | 2.0168 |
| **90%** | 2.4971 | 2.159 | 2.6402 | 2.793 | 2.3231 |
| **95%** | 2.7534 | 2.315 | 2.8452 | 3.0629 | 2.4998 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Lognorm | Weibull | Lognorm | Gamma |
| **No. Tests** | 46 | 46 | 46 | 46 | 27 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 0.024 | 0.00706 | 0.0313 | 0.0258 | 0.0355 |
| **Mode** | 0.00809 | 0.00426 | 0.0213 | 0.0107 | 0.0277 |
| **Std Dev** | 0.0195 | 0.00447 | 0.0187 | 0.023 | 0.0165 |
| **Alpha (α)** | 1.5087 | NA | 1.727 | NA | 4.595 |
| **Beta (β)** | 0.0159 | NA | 0.0351 | NA | 0.00772 |
| **Percentile** | | | | | |
| **5%** | 0.00284 | 0.0023 | 0.00628 | 0.00544 | 0.0133 |
| **10%** | 0.00471 | 0.00283 | 0.00953 | 0.00719 | 0.0166 |
| **25%** | 0.00974 | 0.00403 | 0.0171 | 0.0115 | 0.0234 |
| **50%** | 0.019 | 0.00596 | 0.0284 | 0.0192 | 0.0329 |
| **75%** | 0.0329 | 0.00882 | 0.0424 | 0.0322 | 0.0448 |
| **90%** | 0.0499 | 0.0125 | 0.0569 | 0.0513 | 0.0576 |
| **95%** | 0.0624 | 0.0155 | 0.0662 | 0.0677 | 0.0663 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Gamma | Weibull | Gamma | Weibull |
| **No. Tests** | 46 | 46 | 46 | 46 | 27 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 17.047 | 17.1364 | 15.4838 | 18.9362 | 14.6138 |
| **Mode** | 15.638 | 16.1158 | 14.4382 | 17.3413 | 14.8486 |
| **Std Dev** | 4.901 | 4.182 | 6.4219 | 5.4956 | 4.4451 |
| **Alpha (α)** | 12.101 | 16.791 | 2.589 | 11.873 | 3.657 |
| **Beta (β)** | 1.4088 | 1.021 | 17.435 | 1.595 | 16.204 |
| **Percentile** | | | | | |
| **5%** | 9.8626 | 10.8846 | 5.5353 | 10.8895 | 7.1931 |
| **10%** | 11.1451 | 12.0427 | 7.3096 | 12.3225 | 8.7578 |
| **25%** | 13.5375 | 14.1618 | 10.7747 | 14.9988 | 11.5258 |
| **50%** | 16.58 | 16.7974 | 15.1332 | 18.4073 | 14.6586 |
| **75%** | 20.0486 | 19.742 | 19.7794 | 22.2983 | 17.7174 |
| **90%** | 23.5515 | 22.6665 | 24.0622 | 26.2317 | 20.3541 |
| **95%** | 25.8263 | 24.5447 | 26.6368 | 28.7878 | 21.8726 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Lognorm | Weibull | Lognorm | Triangle |
| **No. Tests** | 3 | 3 | 3 | 3 | 1 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | 0.0231 |
| **Mean** | 0.0178 | 0.023 | 0.0162 | 0.01703 | 0.0137 |
| **Mode** | 0.017 | 0.022 | 0.0169 | 0.01688 | 0.0179 |
| **Std Dev** | 0.00316 | 0.00386 | 0.00249 | 0.00129 | 0.00495 |
| **Alpha (α)** | NA | NA | 7.723 | NA | NA |
| **Beta (β)** | NA | NA | 0.0172 | NA | NA |
| **Percentile** | | | | | |
| **5%** | 0.0132 | 0.0172 | 0.0117 | 0.015 | 0.00455 |
| **10%** | 0.014 | 0.0183 | 0.0129 | 0.01541 | 0.00643 |
| **25%** | 0.0156 | 0.0202 | 0.0147 | 0.01614 | 0.0102 |
| **50%** | 0.0176 | 0.0227 | 0.0164 | 0.01698 | 0.0144 |
| **75%** | 0.0198 | 0.0254 | 0.018 | 0.01787 | 0.0176 |
| **90%** | 0.022 | 0.0281 | 0.0192 | 0.0187 | 0.0196 |
| **95%** | 0.0235 | 0.0298 | 0.0199 | 0.01922 | 0.0206 |

# Grouped – All Furniture Tests containing Fire-Retarded Polyurethane Foams

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Weibull | Lognorm | Lognorm | Lognorm |
| **No. Tests** | 19 | 19 | 18 | 18 | 10 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.7728 | 1.4299 | 2.0156 | 2.0423 | 2.0038 |
| **Mode** | 1.8121 | 1.43 | 1.8445 | 1.9021 | 1.8203 |
| **Std Dev** | 0.5163 | 0.4754 | 0.4975 | 0.45 | 0.5153 |
| **Alpha (α)** | 3.838 | 3.313 | NA | NA | NA |
| **Beta (β)** | 1.960 | 1.594 | NA | NA | NA |
| **Percentile** | | | | | |
| **5%** | 0.9041 | 0.6502 | 1.3118 | 1.3941 | 1.2799 |
| **10%** | 1.0907 | 0.808 | 1.4329 | 1.5088 | 1.4032 |
| **25%** | 1.417 | 1.0942 | 1.6609 | 1.7221 | 1.6361 |
| **50%** | 1.7819 | 1.4269 | 1.9569 | 1.9945 | 1.9406 |
| **75%** | 2.1346 | 1.7589 | 2.3057 | 2.31 | 2.3018 |
| **90%** | 2.4363 | 2.05 | 2.6724 | 2.6365 | 2.684 |
| **95%** | 2.6092 | 2.2195 | 2.9193 | 2.8535 | 2.9425 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Lognorm | Lognorm | Gamma | Gamma | Gamma |
| **No. Tests** | 19 | 19 | 18 | 18 | 10 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 0.0196 | 0.00931 | 0.0281 | 0.0205 | 0.0315 |
| **Mode** | 0.00924 | 0.00657 | 0.0186 | 0.015 | 0.0214 |
| **Std Dev** | 0.0159 | 0.00476 | 0.0164 | 0.0105 | 0.0179 |
| **Alpha (α)** | NA | NA | 2.953 | 3.761 | 3.105 |
| **Beta (β)** | NA | NA | 0.00953 | 0.00544 | 0.0101 |
| **Percentile** | | | | | |
| **5%** | 0.00476 | 0.00375 | 0.00756 | 0.00669 | 0.00885 |
| **10%** | 0.00616 | 0.00447 | 0.0102 | 0.00863 | 0.0118 |
| **25%** | 0.00947 | 0.00599 | 0.0161 | 0.0127 | 0.0184 |
| **50%** | 0.0153 | 0.00829 | 0.025 | 0.0187 | 0.0282 |
| **75%** | 0.0246 | 0.0115 | 0.0368 | 0.0263 | 0.0411 |
| **90%** | 0.0379 | 0.0154 | 0.0501 | 0.0346 | 0.0555 |
| **95%** | 0.049 | 0.0183 | 0.0593 | 0.0403 | 0.0655 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Gamma | Weibull | Lognorm | Triangle |
| **No. Tests** | 19 | 19 | 18 | 18 | 10 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | 24.9126 |
| **Mean** | 17.0165 | 15.3681 | 15.0771 | 20.2562 | 14.0466 |
| **Mode** | 15.7549 | 14.0695 | 13.9755 | 18.2023 | 17.2272 |
| **Std Dev** | 4.6333 | 4.4673 | 6.3347 | 5.5057 | 5.2081 |
| **Alpha (α)** | 13.488 | 11.835 | 2.552 | NA | NA |
| **Beta (β)** | 1.262 | 1.299 | 16.984 | NA | NA |
| **Percentile** | | | | | |
| **5%** | 10.1767 | 8.8284 | 5.3026 | 12.5999 | 4.6324 |
| **10%** | 11.4139 | 9.9925 | 7.0308 | 13.8832 | 6.5511 |
| **25%** | 13.7059 | 12.1672 | 10.4225 | 16.3259 | 10.3583 |
| **50%** | 16.5979 | 14.9374 | 14.7113 | 19.547 | 14.6488 |
| **75%** | 19.8716 | 18.1005 | 19.3032 | 23.4037 | 17.9941 |
| **90%** | 23.1585 | 21.2987 | 23.55 | 27.5214 | 20.5369 |
| **95%** | 25.2848 | 23.3772 | 26.1085 | 30.3245 | 21.8185 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min.** | NA | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Grouped – All Furniture Tests containing Polyurethane Foams

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Weibull | Gamma | Gamma | Weibull |
| **No. Tests** | 65 | 65 | 64 | 64 | 37 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.7749 | 1.5284 | 1.9132 | 2.0257 | 1.8384 |
| **Mode** | 1.6073 | 1.5513 | 1.7366 | 1.8707 | 1.872 |
| **Std Dev** | 0.5455 | 0.4682 | 0.5812 | 0.5603 | 0.551 |
| **Alpha (α)** | 10.587 | 3.629 | 10.836 | 13.069 | 3.718 |
| **Beta (β)** | 0.168 | 1.695 | 0.1766 | 0.1550 | 2.037 |
| **Percentile** | | | | | |
| **5%** | 0.9825 | 0.7478 | 1.0675 | 1.2001 | 0.9161 |
| **10%** | 1.1215 | 0.9119 | 1.2163 | 1.3489 | 1.1118 |
| **25%** | 1.3831 | 1.2027 | 1.496 | 1.625 | 1.4567 |
| **50%** | 1.7194 | 1.5325 | 1.8547 | 1.9742 | 1.8454 |
| **75%** | 2.1063 | 1.8551 | 2.2668 | 2.3703 | 2.2236 |
| **90%** | 2.5 | 2.1335 | 2.6855 | 2.7687 | 2.5487 |
| **95%** | 2.7569 | 2.2939 | 2.9586 | 3.0267 | 2.7357 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Lognorm | Gamma | Lognorm | Gamma |
| **No. Tests** | 49 | 49 | 49 | 49 | 28 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 0.0229 | 0.00768 | 0.0305 | 0.0245 | 0.0347 |
| **Mode** | 0.00872 | 0.00468 | 0.0194 | 0.0111 | 0.0261 |
| **Std Dev** | 0.0181 | 0.0048 | 0.0183 | 0.0204 | 0.0173 |
| **Alpha (α)** | 1.613 | NA | 2.757 | NA | 4.0239 |
| **Beta (β)** | 0.0142 | NA | 0.0111 | NA | 0.00863 |
| **Percentile** | | | | | |
| **5%** | 0.00302 | 0.00253 | 0.00769 | 0.0057 | 0.0119 |
| **10%** | 0.00487 | 0.00312 | 0.0106 | 0.00742 | 0.0152 |
| **25%** | 0.00973 | 0.00442 | 0.017 | 0.0115 | 0.022 |
| **50%** | 0.0184 | 0.00651 | 0.0269 | 0.0188 | 0.0319 |
| **75%** | 0.0313 | 0.00959 | 0.0401 | 0.0307 | 0.0443 |
| **90%** | 0.047 | 0.0136 | 0.0551 | 0.0477 | 0.0579 |
| **95%** | 0.0583 | 0.0167 | 0.0655 | 0.0621 | 0.0672 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Gamma | Weibull | Gamma | Weibull |
| **No. Tests** | 65 | 65 | 64 | 64 | 37 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 17.0403 | 16.6688 | 15.3879 | 19.2334 | 12.747 |
| **Mode** | 15.6647 | 15.5288 | 14.3269 | 17.6578 | 11.7336 |
| **Std Dev** | 4.8416 | 4.3591 | 6.4037 | 5.505 | 5.434 |
| **Alpha (α)** | 12.387 | 14.622 | 2.579 | 12.207 | 2.511 |
| **Beta (β)** | 1.376 | 1.14 | 17.329 | 1.576 | 14.365 |
| **Percentile** | | | | | |
| **5%** | 9.9314 | 10.2025 | 5.4778 | 11.1582 | 4.4006 |
| **10%** | 11.2041 | 11.3829 | 7.2414 | 12.6013 | 5.8618 |
| **25%** | 13.5746 | 13.5594 | 10.6897 | 15.2916 | 8.7456 |
| **50%** | 16.584 | 16.2904 | 15.0331 | 18.7108 | 12.4139 |
| **75%** | 20.0096 | 19.3663 | 19.6685 | 22.6067 | 16.3612 |
| **90%** | 23.4645 | 22.4421 | 23.9449 | 26.5391 | 20.0257 |
| **95%** | 25.7063 | 24.4263 | 26.5172 | 29.092 | 22.2387 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min.** | NA (same as "All Furniture Tests including Non Fire-Retarded Polyurethane Foams") | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA (same as "All Furniture Tests including Non Fire-Retarded Polyurethane Foams") | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Grouped – All Tests containing Non Fire-Retarded Polyurethane Foams

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Gamma | Gamma | Gamma | Weibull |
| **No. Tests** | 66 | 66 | 66 | 66 | 27 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.8094 | 1.6229 | 1.9306 | 2.0517 | 1.659 |
| **Mode** | 1.5437 | 1.4472 | 1.7192 | 1.8635 | 1.6812 |
| **Std Dev** | 0.6933 | 0.534 | 0.6389 | 0.6213 | 0.5133 |
| **Alpha (α)** | 6.811 | 9.2365 | 9.1316 | 10.904 | 3.589 |
| **Beta (β)** | 0.2657 | 0.1757 | 0.2114 | 0.1882 | 1.8414 |
| **Percentile** | | | | | |
| **5%** | 0.8385 | 0.8551 | 1.0128 | 1.1472 | 0.8049 |
| **10%** | 0.9969 | 0.9871 | 1.1703 | 1.3065 | 0.9836 |
| **25%** | 1.3066 | 1.2382 | 1.4702 | 1.6057 | 1.3013 |
| **50%** | 1.7216 | 1.5647 | 1.8606 | 1.9893 | 1.6626 |
| **75%** | 2.2168 | 1.9444 | 2.3148 | 2.4298 | 2.0168 |
| **90%** | 2.7351 | 2.3338 | 2.7812 | 2.8773 | 2.3231 |
| **95%** | 3.0797 | 2.5893 | 3.0873 | 3.169 | 2.4998 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Lognorm | Weibull | Gamma | Gamma |
| **No. Tests** | 66 | 66 | 66 | 66 | 27 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 0.0257 | 0.00813 | 0.0303 | 0.0245 | 0.0355 |
| **Mode** | 0.00711 | 0.00428 | 0.0193 | 0.0111 | 0.0277 |
| **Std Dev** | 0.0219 | 0.00594 | 0.0188 | 0.0182 | 0.0165 |
| **Alpha (α)** | 1.3816 | NA | 1.6545 | 1.8221 | 4.595 |
| **Beta (β)** | 0.01863 | NA | 0.0339 | 0.0135 | 0.00772 |
| **Percentile** | | | | | |
| **5%** | 0.00262 | 0.00224 | 0.00563 | 0.00385 | 0.0133 |
| **10%** | 0.00451 | 0.00284 | 0.0087 | 0.00594 | 0.0166 |
| **25%** | 0.00981 | 0.00423 | 0.016 | 0.0112 | 0.0234 |
| **50%** | 0.0199 | 0.00657 | 0.0272 | 0.0202 | 0.0329 |
| **75%** | 0.0354 | 0.0102 | 0.0413 | 0.0332 | 0.0448 |
| **90%** | 0.0547 | 0.0152 | 0.0561 | 0.0487 | 0.0576 |
| **95%** | 0.0689 | 0.0192 | 0.0658 | 0.0599 | 0.0663 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Gamma | Weibull | Gamma | Weibull |
| **No. Tests** | 66 | 66 | 66 | 66 | 27 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 18.301 | 17.839 | 16.252 | 19.348 | 14.6138 |
| **Mode** | 15.599 | 15.732 | 14.399 | 17.0459 | 14.8486 |
| **Std Dev** | 7.0325 | 6.1309 | 7.4238 | 6.6739 | 4.4451 |
| **Alpha (α)** | 6.7724 | 8.4662 | 2.3241 | 8.4045 | 3.6574 |
| **Beta (β)** | 2.7023 | 2.1071 | 18.343 | 2.3021 | 16.204 |
| **Percentile** | | | | | |
| **5%** | 8.4585 | 9.0852 | 5.1103 | 9.8247 | 7.1931 |
| **10%** | 10.063 | 10.570 | 6.9655 | 11.438 | 8.7578 |
| **25%** | 13.201 | 13.414 | 10.731 | 14.530 | 11.526 |
| **50%** | 17.409 | 17.142 | 15.667 | 18.586 | 14.6586 |
| **75%** | 22.432 | 21.506 | 21.1103 | 23.338 | 17.7174 |
| **90%** | 27.693 | 26.008 | 26.261 | 28.241 | 20.3541 |
| **95%** | 31.191 | 28.973 | 29.409 | 31.471 | 21.8726 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Weibull | Lognorm | Weibull | Weibull | Triangle |
| **No. Tests** | 14 | 14 | 14 | 14 | 3 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | 0.0231 |
| **Mean** | 0.0185 | 0.0282 | 0.0162 | 0.0166 | 0.0137 |
| **Mode** | 0.0120 | 0.0248 | 0.00946 | 0.00805 | 0.0179 |
| **Std Dev** | 0.0114 | 0.00839 | 0.0106 | 0.0117 | 0.00495 |
| **Alpha (α)** | 1.6663 | NA | 1.568 | 1.442 | NA |
| **Beta (β)** | 0.02074 | NA | 0.0181 | 0.0183 | NA |
| **Percentile** | | | | | |
| **5%** | 0.00349 | 0.0167 | 0.00272 | 0.00233 | 0.00455 |
| **10%** | 0.00537 | 0.0186 | 0.0043 | 0.00384 | 0.00643 |
| **25%** | 0.00982 | 0.0222 | 0.00817 | 0.0077 | 0.0102 |
| **50%** | 0.0166 | 0.027 | 0.0143 | 0.0142 | 0.0144 |
| **75%** | 0.0252 | 0.0329 | 0.0223 | 0.0229 | 0.0176 |
| **90%** | 0.0342 | 0.0392 | 0.0308 | 0.0326 | 0.0196 |
| **95%** | 0.0401 | 0.0436 | 0.0364 | 0.0391 | 0.0206 |

# Grouped – All Tests containing Fire-Retarded Polyurethane Foams

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Weibull | Lognorm | Lognorm | Lognorm |
| **No. Tests** | 33 | 33 | 32 | 32 | 10 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.8462 | 1.5024 | 2.1107 | 2.0423 | 2.0038 |
| **Mode** | 1.5845 | 1.4898 | 1.8906 | 1.9021 | 1.8203 |
| **Std Dev** | 0.6952 | 0.5187 | 0.5827 | 0.450 | 0.5153 |
| **Alpha (α)** | 7.052 | 3.1772 | NA | NA | NA |
| **Beta (β)** | 0.262 | 1.678 | NA | NA | NA |
| **Percentile** | | | | | |
| **5%** | 0.8695 | 0.6589 | 1.3029 | 1.3941 | 1.2799 |
| **10%** | 1.0299 | 0.8264 | 1.4377 | 1.5088 | 1.4032 |
| **25%** | 1.3425 | 1.1337 | 1.6947 | 1.7221 | 1.6361 |
| **50%** | 1.7598 | 1.4952 | 2.0346 | 1.9945 | 1.9406 |
| **75%** | 2.256 | 1.8597 | 2.4427 | 2.31 | 2.3018 |
| **90%** | 2.7743 | 2.1818 | 2.8795 | 2.6365 | 2.684 |
| **95%** | 3.1183 | 2.3702 | 3.1774 | 2.8535 | 2.9425 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Gamma | Gamma | Gamma | Gamma |
| **No. Tests** | 33 | 33 | 32 | 32 | 10 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 0.0187 | 0.0115 | 0.0275 | 0.0205 | 0.0315 |
| **Mode** | 0.00894 | 0.00672 | 0.0158 | 0.015 | 0.0214 |
| **Std Dev** | 0.0136 | 0.00746 | 0.0179 | 0.0105 | 0.0179 |
| **Alpha (α)** | 1.9117 | 2.392 | 2.3616 | 3.7614 | 3.1053 |
| **Beta (β)** | 0.00980 | 0.00482 | 0.0116 | 0.00544 | 0.0101 |
| **Percentile** | | | | | |
| **5%** | 0.00314 | 0.00252 | 0.00593 | 0.00669 | 0.00885 |
| **10%** | 0.00477 | 0.00359 | 0.00846 | 0.00863 | 0.0118 |
| **25%** | 0.00879 | 0.00605 | 0.0143 | 0.0127 | 0.0184 |
| **50%** | 0.0156 | 0.00998 | 0.0237 | 0.0187 | 0.0282 |
| **75%** | 0.0253 | 0.0153 | 0.0366 | 0.0263 | 0.0411 |
| **90%** | 0.0368 | 0.0215 | 0.0514 | 0.0346 | 0.0555 |
| **95%** | 0.0451 | 0.0259 | 0.0619 | 0.0403 | 0.0655 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Weibull | Weibull | Lognorm | Triangle |
| **No. Tests** | 33 | 33 | 32 | 32 | 10 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | 24.913 |
| **Mean** | 18.1887 | 16.572 | 16.366 | 20.256 | 14.047 |
| **Mode** | 15.2753 | 15.661 | 14.447 | 18.202 | 17.227 |
| **Std Dev** | 7.2794 | 6.661 | 7.5205 | 5.5057 | 5.2081 |
| **Alpha (α)** | 6.2433 | 2.681 | 2.3088 | NA | NA |
| **Beta (β)** | 2.9133 | 18.640 | 18.473 | NA | NA |
| **Percentile** | | | | | |
| **5%** | 8.0819 | 6.1559 | 5.103 | 12.600 | 4.632 |
| **10%** | 9.7033 | 8.0519 | 6.97 | 13.883 | 6.551 |
| **25%** | 12.9008 | 11.712 | 10.769 | 16.326 | 10.358 |
| **50%** | 17.2273 | 16.258 | 15.761 | 19.547 | 14.649 |
| **75%** | 22.4327 | 21.055 | 21.280 | 23.404 | 17.994 |
| **90%** | 27.9169 | 25.441 | 26.511 | 27.521 | 20.537 |
| **95%** | 31.5772 | 28.065 | 29.712 | 30.325 | 21.819 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min.** | NA | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Grouped – All Tests containing Polyurethane Foams

| $CO_2$ Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Weibull | Gamma | Gamma | Weibull |
| **No. Tests** | 99 | 99 | 98 | 98 | 37 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 1.8177 | 1.575 | 1.9748 | 2.0508 | 1.8426 |
| **Mode** | 1.5528 | 1.5622 | 1.772 | 1.8775 | 1.8746 |
| **Std Dev** | 0.694 | 0.543 | 0.6329 | 0.5962 | 0.5556 |
| **Alpha (α)** | 6.861 | 3.181 | 9.735 | 11.834 | 3.693 |
| **Beta (β)** | 0.265 | 1.759 | 0.203 | 0.1733 | 2.042 |
| **Percentile** | | | | | |
| **5%** | 0.8452 | 0.692 | 1.0611 | 1.1781 | 0.9136 |
| **10%** | 1.0042 | 0.8671 | 1.2194 | 1.3334 | 1.1102 |
| **25%** | 1.3146 | 1.189 | 1.5194 | 1.6236 | 1.4572 |
| **50%** | 1.7302 | 1.5675 | 1.9076 | 1.9933 | 1.8491 |
| **75%** | 2.2258 | 1.9491 | 2.3572 | 2.4154 | 2.2309 |
| **90%** | 2.7443 | 2.2861 | 2.8169 | 2.8422 | 2.5595 |
| **95%** | 3.0889 | 2.4833 | 3.1179 | 3.1196 | 2.7485 |

| CO Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Lognorm | Weibull | Gamma | Gamma |
| **No. Tests** | 99 | 99 | 98 | 98 | 37 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 0.0242 | 0.00938 | 0.0296 | 0.0236 | 0.0347 |
| **Mode** | 0.00742 | 0.00456 | 0.0188 | 0.0118 | 0.0261 |
| **Std Dev** | 0.0201 | 0.00737 | 0.0184 | 0.0167 | 0.0173 |
| **Alpha (α)** | 1.443 | NA | 1.651 | 1.996 | 4.024 |
| **Beta (β)** | 0.0167 | NA | 0.0331 | 0.0118 | 0.00863 |
| **Percentile** | | | | | |
| **5%** | 0.00265 | 0.00236 | 0.00548 | 0.00418 | 0.0119 |
| **10%** | 0.00448 | 0.00303 | 0.00847 | 0.00626 | 0.0152 |
| **25%** | 0.0095 | 0.00462 | 0.0156 | 0.0113 | 0.022 |
| **50%** | 0.0189 | 0.00738 | 0.0265 | 0.0198 | 0.0319 |
| **75%** | 0.0331 | 0.0118 | 0.0404 | 0.0318 | 0.0443 |
| **90%** | 0.0508 | 0.0179 | 0.0549 | 0.0459 | 0.0579 |
| **95%** | 0.0638 | 0.0231 | 0.0644 | 0.056 | 0.0672 |

| Heat of Combustion (MJ/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | Gamma | Weibull | Weibull | Gamma | Weibull |
| **No. Tests** | 99 | 99 | 98 | 98 | 37 |
| **Parameter** | | | | | |
| **Min.** | 0 | 0 | 0 | 0 | 0 |
| **Max.** | +Inf | +Inf | +Inf | +Inf | +Inf |
| **Mean** | 18.2759 | 17.2866 | 16.2796 | 19.557 | 12.747 |
| **Mode** | 15.5256 | 16.7814 | 14.4099 | 17.3877 | 11.7336 |
| **Std Dev** | 7.0897 | 6.4457 | 7.4477 | 6.5135 | 5.434 |
| **Alpha (α)** | 6.645 | 2.916 | 2.320 | 9.015 | 2.511 |
| **Beta (β)** | 2.750 | 19.382 | 18.374 | 2.169 | 14.365 |
| **Percentile** | | | | | |
| **5%** | 8.3712 | 6.9977 | 5.1079 | 10.2094 | 4.4006 |
| **10%** | 9.9802 | 8.9574 | 6.966 | 11.8107 | 5.8618 |
| **25%** | 13.1324 | 12.6418 | 10.7399 | 14.8624 | 8.7456 |
| **50%** | 17.3677 | 17.0925 | 15.6893 | 18.8388 | 12.4139 |
| **75%** | 22.433 | 21.6799 | 21.1517 | 23.4709 | 16.3612 |
| **90%** | 27.7453 | 25.8011 | 26.3221 | 28.23 | 20.0257 |
| **95%** | 31.2806 | 28.2383 | 29.4835 | 31.3557 | 22.2387 |

| Soot Yield (kg/kg) | | | | | |
|---|---|---|---|---|---|
| **Stages** | **All** | **G** | **TS** | **T** | **S** |
| **Distrib.** | NA | | | | |
| **No. Tests** | NA | | | | |
| **Parameter** | | | | | |
| **Min.** | NA (same as "All Tests containing Non Fire-Retarded Polyurethane Foams") | | | | |
| **Max.** | | | | | |
| **Mean** | | | | | |
| **Mode** | | | | | |
| **Std Dev** | | | | | |
| **Alpha (α)** | | | | | |
| **Beta (β)** | | | | | |
| **Percentile** | | | | | |
| **5%** | NA (same as "All Tests containing Non Fire-Retarded Polyurethane Foams") | | | | |
| **10%** | | | | | |
| **25%** | | | | | |
| **50%** | | | | | |
| **75%** | | | | | |
| **90%** | | | | | |
| **95%** | | | | | |

# Appendix B Other Data Sources

**Unused data sources, tube furnace tests and data sources to be followed up**

## *B.1 Unused Data Sources*

Other than the data sources presented above, many other sources listed below were also investigated. However, for various reasons, these were not deemed suitable during the initial data acquisition stage.

### B.1.1 Initial Fires Database

The Initial Fires' database from Lund University (Särdqvist, 1993) contains a wealth of information for a wide range of materials tested in full scale, including some unpublished data. The database is classified into different construction components and test items include individual items such as, upholstered furniture and groups of items in room scenarios such as bedrooms. Unfortunately, it did not have any electronic mass records for conversion into yields. Furthermore, due to limited resources and computational capacity, data were recorded at 30s intervals. Since combustion is a rapidly changing dynamic phenomenon, measurements at 30s intervals may not be able to adequately capture necessary details of the combustion behaviour.

### B.1.2 SP Database (CBUF Items)

A large collection of test results from bench-scale to full-scale room tests have been organised in SP's Fire Data Base (Ljung, 2005). Included in the database are the commercially available furniture item test results from the Combustion Behaviour of Upholstered Furniture (CBUF) research program, along with many other test results from different research institutes. Unfortunately, although time series for heat release rate (kW), SEA ($m^2$/kg) and smoke production rate (SPR in $m^2$/s) were available, mass records were not available for yields to be calculated as can be seen from Figure B.1.

| Keyword | Value |
|---|---|
| Material1 | Fabric: 100% Cotton FR Treated; Interliner: Kevlar |
| Material2 | CMHR Urethane Foam |
| Material3 | |
| Material4 | |
| Product | |
| Object | |
| Scenario | |
| Method | ISO 5660 |
| Reference | CBUF - Fire Safety of Upholstered Furniture, EC Report EUR 16477 EN, contact SP for more information. |
| Comment | |
| Owner | |
| IsPublic | 1 |
| ImportDate | 2005-11-01 10:09:34 |

| Scalar | Value |
|---|---|
| Flux (kW/m2) | |
| tig (s) | |
| qmax (kw/m2) | 98.00 |
| qtotal (MJ/m2) | 18.00 |
| q180 (kw/m2) | |
| q300 (kw/m2) | |
| Mass loss (g) | 19.700 |
| DHc (MJ/kg) | |
| Peak smoke production (m2/m2s) | 0.0212 |
| Total smoke produced (m2/m2) | 7.203 |
| Specific extinction area (avg) (m2/kg) | 9.060 |
| Area (m2) | |
| Thickness (mm) | |
| Density (kg/m3) | |

| Time (s) | HRR (kW/m2) | SEA (m2/kg) | SPR (m2/s) |
|---|---|---|---|
| 0 | 7.7 | 2 | 0.0001 |
| 5 | 14.5 | 0 | 0.0001 |
| 10 | 96.3 | 48 | 0.0042 |
| 15 | 97.9 | 26 | 0.0028 |
| 20 | 68.0 | 22 | 0.0009 |
| 25 | 54.8 | 40 | 0.0017 |

**Figure B12.1 SP Fire Data Base Format**
**(Reproduced from Ljung, 2005)**

### B.1.3 NIST Furniture Calorimeter Data – Mock-Up Chair

As part of National Institute of Standards and Technology's (NIST) research progress to correlate larger scale performance from small-scale tests, 27 material combinations were tested. These include both the bench-scale and four-cushion mock-up tests (Figure B.2), tested in accordance with the California Technical Bulletin 133 standards (California Technical Bulletin 133, 1991). Bench-scaled data contained all essential data required for the purpose of this research work, unfortunately mock-up chairs lacked a form of mass record (either as mass record or mass loss rate record). Hence, the mock-up chair results were not used since conversions from fire species productions to yields were not possible.

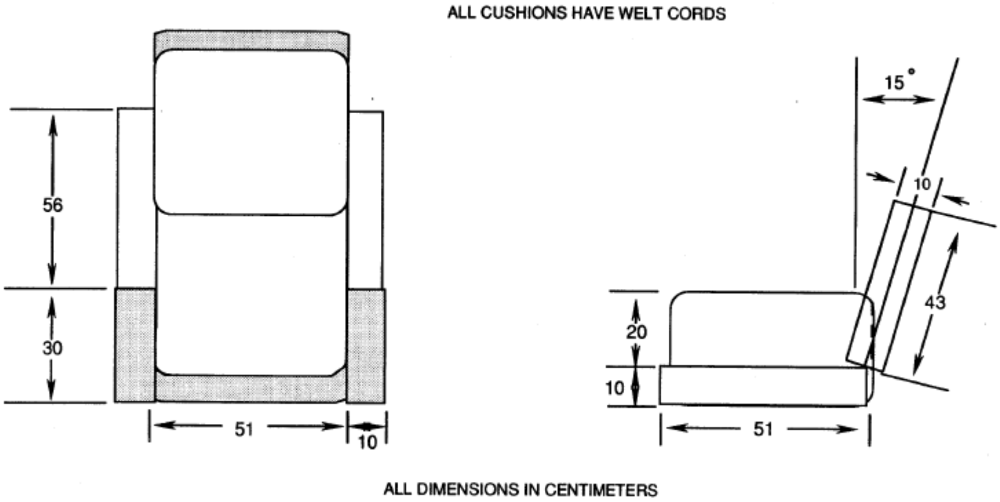


**Figure B.2 Mock-up Cushion Arrangements for the Californian Technical Bulletin 133 tests (Reproduced from Ohlemiller and Shields, 1995)**

### B.1.4 Firestone's CSIRO Data

CSIRO's test facilities in Melbourne had made several furniture calorimeter and cone calorimeter test results available for Firestone's research (1999). These tests were conducted prior to Firestone's research in 1993, to examine burning behaviour of sofas, built over a metal frame, conforming to the Swedish Nordtest standard (NORDTEST, 1987). However, due to different reasons, both the cone calorimeter and furniture calorimeter data sets from CSIRO were not suitable for this research work. For the cone calorimeter tests, the mass flow rates through the exhaust duct were not given. For furniture calorimeter tests, the mass measurement was not available for mass loss rate to be calculated.

### B.1.5 Chung's Native Korean Wood Tests

To investigate combustion behaviour of native Korean wood species, a series of wood samples were tested under the cone calorimeter by Chung (2009). The test results were made available for this research; however, mass flow rate through the exhaust duct was assumed as a constant value of 24 l/s. As the mass flow rate is critical in determining accurate fire species production, which in turn determines the fire species yields, a constant value was not considered adequate for the purpose of this research.

### B.1.6 The National Fire Protection Association (NFPA)

The National Fire Protection Association (NFPA) develops, publishes, and distribute more than 300 consensus codes and standards to "reduce the worldwide burden of fire and other hazards on the quality of life" (NFPA, 2010). Unfortunately, NFPA's fire data base mainly consists of fire incident reports from actual fires, not test data (Fahy, 2009). The research program director had also provided direction into specific reports, which requires direct correspondence with the researchers for further information (Grant, 2009).

### B.1.7 The Society of Fire Protection Engineers (SFPE)

The Society of Fire Protection Engineers' (SFPE) contains a wealth of information and data for research and practical engineering designs. As it is an edited collection of literature, the data available from each literature source is only available through direct correspondence with author, and not through the society itself. Email correspondence with SFPE has confirmed that the only information that is available is those already published in the SFPE Handbook.

## *B.2 Tube Furnace Results*

Apart from bench-scale, medium-scale, and full scale tests, other scales and forms of fire tests were also explored. Tube furnace test results (ISO TS 19700) were another available source with time series data. The steady-state tube furnace is designed to establish constant combustion conditions by feeding the sample continuously into a stationary furnace (Figure B.3). It is designed to accurately facilitate the proper analysis of toxic fire products and is capable of measuring trace elements such as HCN to high accuracy using the Fourier Transform InfraRed Spectroscopy (FTIR). Different controlled fire stages can also be reproduced by controlling the ventilation conditions.

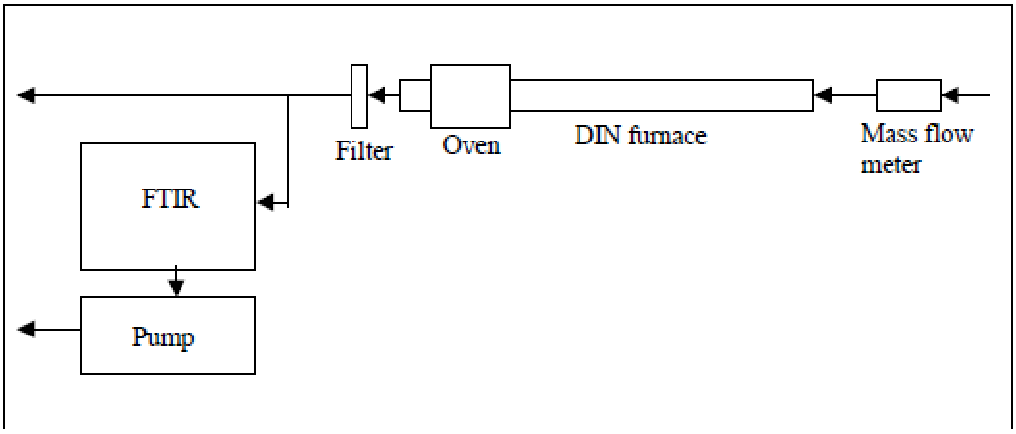


**Figure B.3** **Schematic Representation of the Tube Furnace Apparatus (Reproduced from Simonson et al., 2000)**

Although the tube furnace method was created to achieve constant material decomposition for simulating different fire conditions, without a mass scale, this cannot be verified. Since the mass loss rate profile directly influences yield magnitudes, it was essential that the actual mass loss rate be accurately quantified inside the tube. Consequently, carbon balancing was done for all tube furnace tests using CO and $CO_2$ measured in the tube. This procedure is discussed in more detail in Chapter 5.

### B.2.1 Anderson's LDPE Results

Seven Low-Density PolyEthylene (LDPE) tests were conducted by Anderson (2008). Being a simple polymer structure with a well-defined chemical composition of $(C_3H_6)_n$, reasonable results were achieved in re-constructing the actual mass loss rate through carbon balancing (Chapter 5). Knowing CO and $CO_2$ productions and the chemical composition of LDPE, mass loss rates were easily derived. However, since the carbon retrieval ranged between 73% and 102%, with LDPE not commonly used in typical residential or commercial environments, it was not included in the final analysis.

### B.2.2 Simonson et al.'s Results

The objective of Simonson's (2000) research was to investigate CO and HCN yields as a function of ventilation conditions and their effects on occupant escape abilities. A pilot laboratory investigation using the tube furnace was conducted for non-flaming (i.e. pyrolysing) conditions and flaming (i.e. fire) conditions. A selection of nitrogen containing material commonly found in domestic environments was tested, including: wool, nylon, synthetic rubber, melamine and polyurethane foam (Simonson *et al.*, 2000).

With assistance from Ingham (2009), approximations on chemical compositions were made for Simonson et al.'s tube furnace results. However, due to observed soot formation and uncertain chemical compositions, the carbon counting method was significantly compromised, yielding a retrieval rate between 2% and 183%.

From this, it became evident that tube furnace tests were not suitable for the purpose of this research, owing to the limited amount of mass involved and the great uncertainties associated with mass loss rate profiling. This is especially true for chemically complex materials that are commonly found in most combustion scenarios. Without an accurate mass record, tube furnace data collected from Anderson (2008) and Simonson et al. (2000) could not be included in this research.

## *B.3 Other sources to follow up*

Due to time and financial constraints, a few other sources could not be further explored. Restrictions such as difficulties in retrieving archived data or extracting data from floppy disks have prevented some information to be included. Some commercially sensitive data also meant that specific permission must be sought before they can be used for other research purposes. These sources are listed below, which could serve as the starting point for further expansion of this database.

### B.3.1 SP Technical Research Institute of Sweden Database

The SP Technical Research Institute provides a wide range of services for material (or composite product) performance evaluations when exposed to fire, assessing their respective fire risks for industry and other research organisations. Often, these are done in conjunction with universities and research institutes. Extensive effort has been invested into material certification, both in Sweden and other countries.

Apart from the SP database (Ljung, 2005), a collection of other individual test results are also available. Regrettably, due to the geographical distance and amount of data involved, a visit to the SP research institute is preferred over sending data indiscriminately. To avoid misusing or misunderstanding the test results, personal collection and first hand experimental comprehension is necessary to correctly appreciate the purposes of the research (Simonson, 2009).

### B.3.2 Bryner et al.'s Station Nightclub Fire Data

As part of NIST's investigation procedure of the Station nightclub fire (Bryner et al., 2007), a computer fire model was used to reconstruct the fire development within the nightclub. Lacking adequate literature values to model the ignition and fuel load capacity, the essential material properties were obtained through a series of bench-scale tests on the interior lining materials, including the wall panelling, carpeting, ceiling tiles, and polyurethane foam. In addition to the small-scale tests, a series of full-scale experimental mock-up tests were also conducted to collect additional data on fire growth and smoke movement. Unfortunately, correspondence with one of its authors, Mr. Madrzykowski, has found that this collection of valuable information has been archived and could not be retrieved in time during the course of this research work.

### B.3.3 NIST Database (Updated)

Despite the availability of newer data since the publication NIST's FASTData 1.0 Database in 1999, there has not been a "concerted effort to collect it into a single publication" (Peacock, 2009). Test results must be obtained from the researchers individually, most would have to go through the archiving system, and converting information from floppy disks in some cases. One such example is the Station Nightclub Fire research mentioned above (Bryner et al., 2007), where data retrieval requires much effort by the researchers themselves outside their existing busy schedules.

# Appendix C Carbon Counting Calculations

As a closer examination to determine the amount of carbon captured during experimental measurement, a carbon counting procedure was applied to all "simple materials" tests collected in this database. Materials involving only one material are defined as simple materials in this research, and include the following:

- 3 standard polyurethane foams test from Firestone's (1999) research ("S0", foam only, no veering fabrics),
- 3 high resilience polyurethane foams tests from Firestone's (1999) research ("HR0" foam only, no veering fabrics),
- 12 nylon carpet tests from Johnson's (2008) research,
- 12 polypropylene carpet tests from Johnson's (2008) research, and
- 12 wool carpet tests from Johnson's (2008) research

It should be noted that despite being classified as "simple materials", backing fibres have also been involved in the combustion for all carpet tests. This complicates the amount of carbon loss during combustion as all materials have been assumed as the carpeting material of nylon, polypropylene, and wool.

Furthermore, the chemical equation for flexible polyurethane foams is not exact, and a range of possibly chemical formula has been determined by Tewarson (2002) as modifications were done to the foams to suit different foam applications as shown in Table C.1.

**Table C.1 Empirical Formula for Flexible Polyurethane Foams**

| Flexible Polyurethane (PU) Foams | Chemical Formula | PU Molecular Weight | Mass Ratio of C Atom to PU molecule |
|---|---|---|---|
| GM21 | $CH_{1.8}O_{0.30}N_{0.05}$ | 19.3 | 0.62 |
| GM23 | $CH_{1.8}O_{0.35}N_{0.06}$ | 20.24 | 0.59 |
| GM25 | $CH_{1.7}O_{0.32}N_{0.07}$ | 19.8 | 0.60 |
| GM27 | $CH_{1.7}O_{0.33}N_{0.08}$ | 20.1 | 0.60 |

Gottuk and Lattimer (2002) have also derived a general empirical chemical formula of $\mathbf{CH_{1.74}O_{0.323}N_{0.0698}}$ for flexible polyurethane foams. This formula generates a similar carbon atom to the PU molecule ratio (19.89 g/mol PU) of 0.60, and will be assumed in for all polyurethane foams.

## *C.1 Carbon Atoms Measured in the form of $CO_2$ and CO*

To illustrate the steps taken to derive the carbon retrieval percentages in Table 8.5, two examples will be used. One example is taken from Firestone's (1999) standard polyurethane foam and the other is taken from Johnson's (2008) nylon carpet.

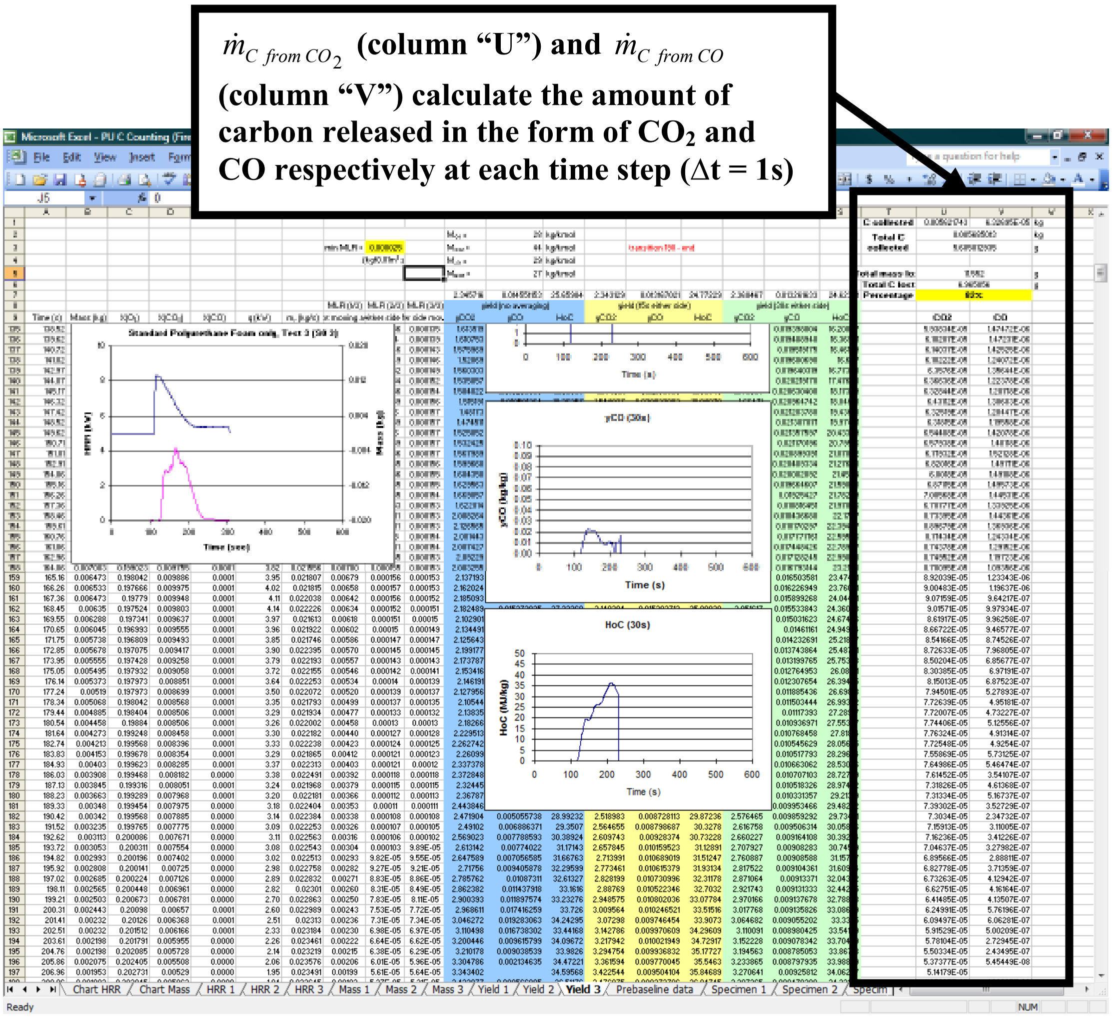


**Figure C.1 Spreadsheet calculation for fire species yields and carbon counting – standard polyurethane foam test 3 ("S0") at 35 kW/m$^2$ irradiance (Adapted from Firestone, 1999)**

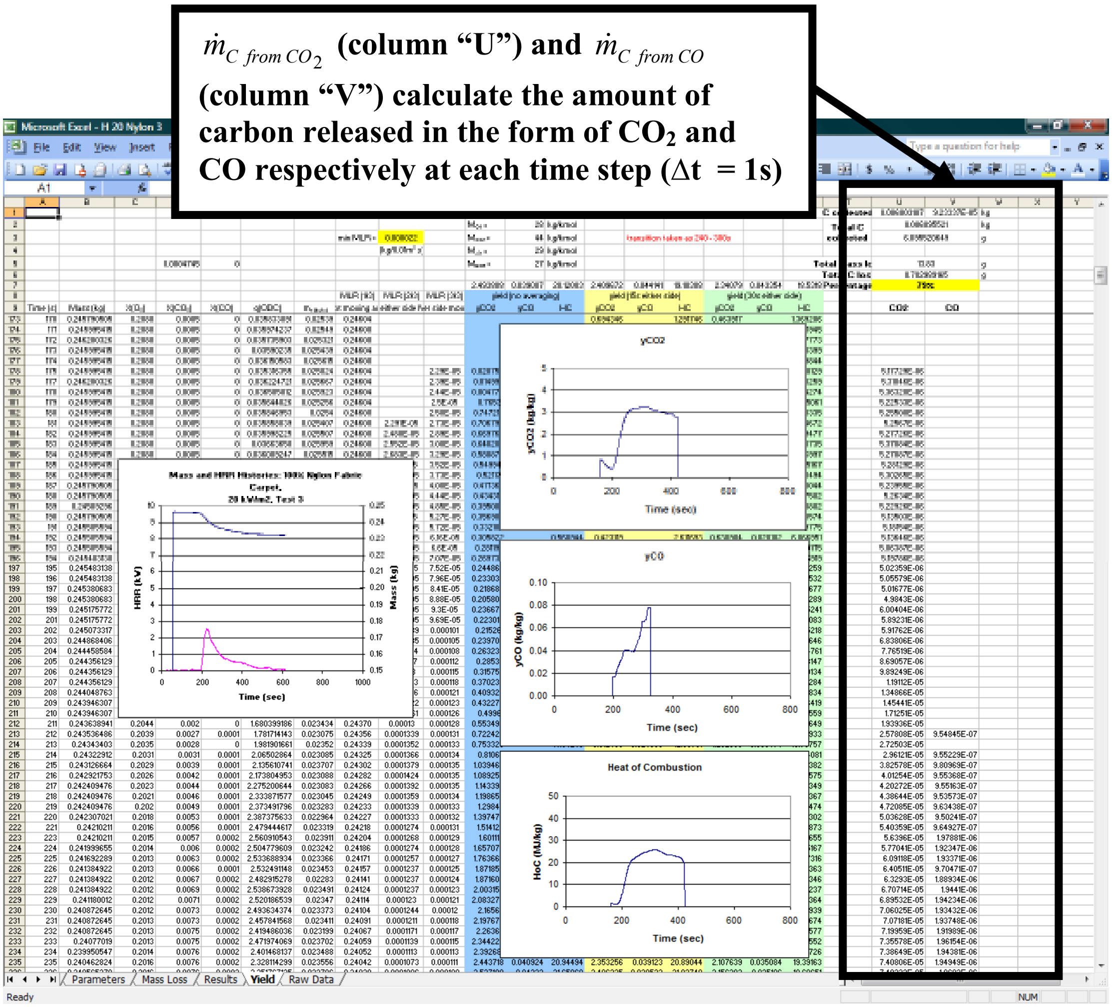


**Figure C.2** **Spreadsheet calculation for fire species yields and carbon counting – Nylon carpet test 3 at 20 kW/m$^2$ irradiance (Adapted from Johnson, 2008)**

From Chapter 4, the yield equations have been simply expressed as:

$$y_i = \frac{m_i}{m_{fuel}} \qquad \text{Equation C.1}$$

Where

| | | | |
|---|---|---|---|
| $y_i$ | = | yield of species i | (kg/kg or -) |
| $m_i$ | = | mass of species i generated | (kg or kg/s) |
| $m_{fuel}$ | = | mass of the gaseous fuel supplied | (kg or kg/s) |

Alternatively, including all parameter variables, Gottuk and Lattimer (2002) have derived the yield calculation below:

$$y_i = \frac{(\dot{m}_{fuel} + \dot{m}_{air}) \times \chi_i \times \dfrac{M_i}{M_{air}}}{\dot{m}_{fuel}}$$ Equation C.2

Since the mass flow rate through the calorimeter's exhaust duct ($\dot{m}_{duct}$) includes both vaporised fuel ($\dot{m}_{fuel}$) and entrained air ($\dot{m}_{air}$), the equation can be simplified to:

$$y_i = \frac{\dot{m}_{duct} \times \chi_i \times \dfrac{M_i}{M_{air}}}{\dot{m}_{fuel}}$$ Equation C.3

Where

| | | | |
|---|---|---|---|
| $y_i$ | = | yield of species i | (kg/kg or -) |
| $\dot{m}_{fuel}$ | = | mass loss rate of fuel | (kg/s) |
| $\dot{m}_{air}$ | = | mass air entrainment rate | (kg/s) |
| $\dot{m}_{duct}$ | = | mass flow through the duct | (kg/s) |
| $\chi_i$ | = | mole fraction of species i | (-) |
| $M_i$ | = | molecular weight of species i, see Table 4.1 | (g/mol) |
| $M_{air}$ | = | molecular weight of incoming and exhaust air | (29g/mol) |

**Table C.2 Molecular weights for common fire gases (Adapted from Loss, 2003)**

| Gas | Molecular Weight (g/mol) |
|---|---|
| Carbon Monoxide (CO) | 28 |
| Carbon Dioxide ($CO_2$) | 44 |
| Water Vapour ($H_2O$) | 18 |
| Hydrogen Bromide (HBr) | 81 |
| Hydrogen Chloride (HCl) | 36 |
| Hydrogen Cyanide (HCN) | 27 |

For carbon counting, only the carbon-containing fire species productions are of concern, which is the numerator in Equation C.3. Carbon-containing fire species include the $CO_2$, CO, HCN, and soot. However, due to limited data, only $CO_2$ and CO could be accounted for.

Soot yield data have been references from Tewarson for similar items, which are homogenous samples without the backing fibre used in Johnson's (2008) carpet tests (Refer to Table 8.5 for these soot yield values).

To calculate the amount of carbon atoms released through combustion, the yield of carbon atoms from $CO_2$ and CO can be calculated by taking the numerator in Equation C.3 and multiplying the ratio of carbon atom (12 g/mol) to the $CO_2$ molecule (44 g/mol) or CO molecule (28 g/mol).

Carbon yield through $CO_2$ production can be derived by applying Equation C.4 below:

$$\begin{aligned} m_{C\ from\ CO_2} &= \dot{m}_{duct} \times \delta t \times \chi_{CO_2} \times \frac{M_{CO_2}}{M_{air}} \times \frac{M_C}{M_{CO_2}} \\ &= \dot{m}_{duct} \times 1\ s \times \chi_{CO_2} \times \frac{44}{29} \times \frac{12}{44} \\ &= \dot{m}_{duct} \times 1\ s \times \chi_{CO_2} \times \frac{12}{29} \end{aligned} \qquad \text{Equation C.4}$$

Similarly for carbon yield through CO production (Equation C.5):

$$\begin{aligned} m_{C\ from\ CO} &= \dot{m}_{duct} \times \delta t \times \chi_{CO} \times \frac{M_{CO}}{M_{air}} \times \frac{M_C}{M_{CO}} \\ &= \dot{m}_{duct} \times 1\ s \times \chi_{CO} \times \frac{28}{29} \times \frac{12}{28} \\ &= \dot{m}_{duct} \times 1\ s \times \chi_{CO} \times \frac{12}{29} \end{aligned} \qquad \text{Equation C.5}$$

## *C.2 Carbon Atoms Lost during Combustion*

Once the carbon production rates from $CO_2$ and CO have been calculated for each time frame, the total carbon lost through $CO_2$ and CO can then be determined by summing up columns "U" ($\dot{m}_{C\ from\ CO_2}$) and "V" ($\dot{m}_{C\ from\ CO}$) in Figures C.1 and C.2 over each time interval ($\Delta t$ = 1s).

Total amount of carbon lost can be estimated from the sample material's chemical compositions that are already given in Table 8.5. After determining the total mass lost, calculate the molecular mass (for example, column 3 in Table C.1), and then simply use the ratio of carbon atom mass (12 g/mol) to the material's molecular mass (for example, column 4 in Table C.1) to calculate the amount of carbon atoms loss from the samples. An example is shown below for Firestone's standard foam test ("S0", test 3).

| | | |
|---|---|---|
| **Initial Mass** | = 13.1 g | |
| **Final Mass** | = 1.5 g | |
| **Total Mass Lost** | = 13.1 – 1.5 | = 11.6 g |
| **Empirical Formula** | = $CH_{1.74}O_{0.323}N_{0.0698}$ (Gottuk and Lattimer, 2002) | |
| **Molecular Weight** | = 12 + 1*1.74 + 16*0.323 + 14*0.0698 | = 19.89 g/mol |
| **Mass ratio of carbon (C) atom to polyurethane foam molecule** | = 12 / 19.89 | = 0.60 |
| **Total carbon loss during the entire combustion process** | = 11.6 * 0.60 | = 7.0 g |

The final carbon retrieval percentages were derived by dividing the results in Section C.1 (C captured by instruments) by the corresponding results in Section C.2 (C lost during combustion) for each material, as presented in Table 8.5.

# Appendix D UCFIRE User Feedback

Initially UCFIRE, a semi-automated data reduction application developed by Tobeck (2007), was used to mechanically reduce all experimental data. Unfortunately, several technical difficulties were encountered during trial use. To facilitate future modification to UCFIRE, some user experiences are documented here in Appendix D.

To reduce experimental data into species yields, Tobeck created UCFIRE to import raw experimental data and output graphs and calculated yield values. Raw data is read using a pre-defined input file, requiring certain data to be stored in time series format in order to process the yield calculations (Tobeck, 2007). Data can be then be processed and stored for meaningful analysis later on for a variety of test types, including the Cone Calorimeter, Furniture Calorimeter, Room/Corner Test, LIFT and Ignitability Apparatus Tests.

It was proposed by Tobeck that "Any data reduction which is performed on this fire test data should be done in an entirely mechanistic fashion rather than rely on human intuition which is subjective". Therefore, using the algorithms created and modified by Tobeck, minimal user manipulation is required once all the input data are properly entered, incorporating the correct time delays (Enright, 1999).

To calculate the mass loss rate, the Savitzky-Golay algorithm (Staggs, 2005) was recommended by Tobeck, which was further modified "to autonomously filter other noisy events that occurred during the fire tests" (Tobeck, 2007). The ASTM E 1354 mass loss rate was also offered as an alternative mass loss rate algorithm. However, for the cone calorimeter tests (MDF and PMMA by Pau (2007)) and the furniture calorimeter tests (B6S1 and C7S1 by Enright (1999)), the Savitzky-Golay algorithm has given superior estimates of the mass loss rate.

## *D.1 UCFIRE Tolerance and Threshold Setting*

Once the modified Savitzky-Golay filtering algorithm is selected, a setting dialogue appears for the polynomial orders and the mass loss rate tolerance and threshold

(Figure D.1). While the polynomial order parameters have been recommended by Tobeck through a trial and error process, the last two parameters relate to the mass loss rate threshold limits. These two parameters allow a user-define tolerance level, relative to the maximum mass loss rate or using the resolution of the mass measurements. Unfortunately, a consistent mass loss rate cut-off cannot be achieved when using the maximum mass loss rate as the reference point. This is because the maximum value is a highly variable reference point and can be excessively high in some cases, hence lifting the mass loss rate cut-off limit.

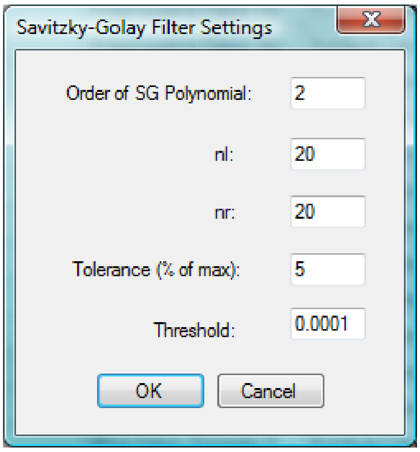


**Figure D.1 Savitzky-Golay Filter Settings in UCFIRE (Reproduced from Tobeck, 2007)**

The effects of using a different tolerance level can be seen from Figures D.2 a), b), c) and d) and Figures D.3 a), b), c) and d), by fixing the threshold at the recommended value of 0.0001kg/s (0.1g/s). Tolerance levels have been chosen at 5% to 0.1% to illustrate the differences this criterion has on the mass loss rate profile (Figures D.2 a) and D.3 a)), the $CO_2$ yield (Figures D.2 b) and D.3 b)), and CO yield (Figures D.2 c) and D.3 c)) and the heat of combustion (Figures D.2 d) and D.3 d)).

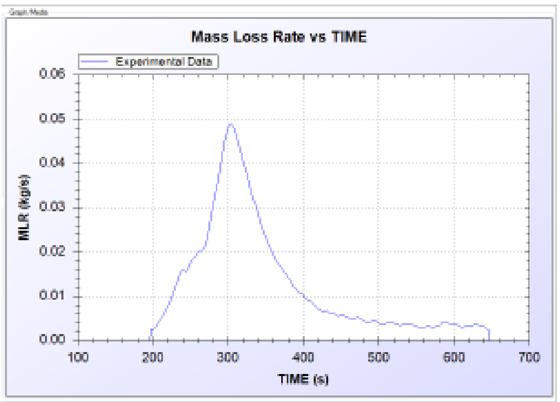


**Figure D.2 UCFIRE Tolerance Comparison**
for Polypropylene Fabric and Dom. ("PPDFS5")
Furn. Foam (Adapted from Hill, 2003)
5% of max MLR, 0.1 g threshold
**a) Mass Loss Rate Profile**

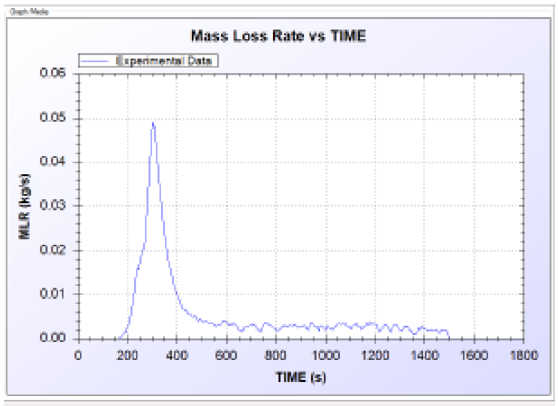


**Figure D.3 UCFIRE Tolerance Comparison**
for Polypropylene Fabric and Dom. ("PPDFS5")
Furn. Foam (Adapted from Hill, 2003)
0.1% of max MLR, 0.1 g threshold
**a) Mass Loss Rate Profile**

By lowering the tolerance level from 5% to 0.1% of the maximum mass loss rate, the experimental time frame has increased from approximately 650 sec to approximately 1500 sec. As not all experiments would have a maximum mass loss rate as high (or low) as PPDFS5, a consistent mass loss rate should be applied to give consistent results (Section 5.3).

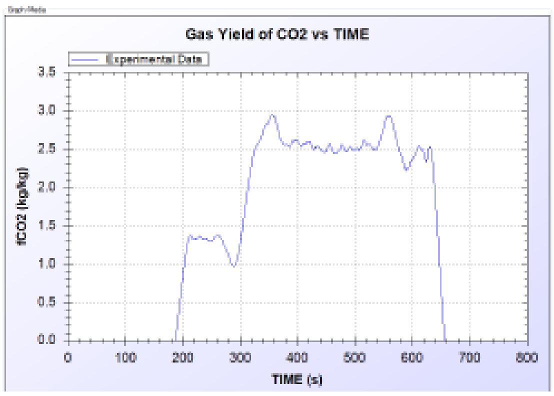


**Figure D.2 UCFIRE Tolerance Comparison**
for Polypropylene Fabric and Dom. ("PPDFS5")
Furn. Foam (Adapted from Hill, 2003)
5% of max MLR, 0.1 g threshold
**b) $CO_2$ Yield Profile**

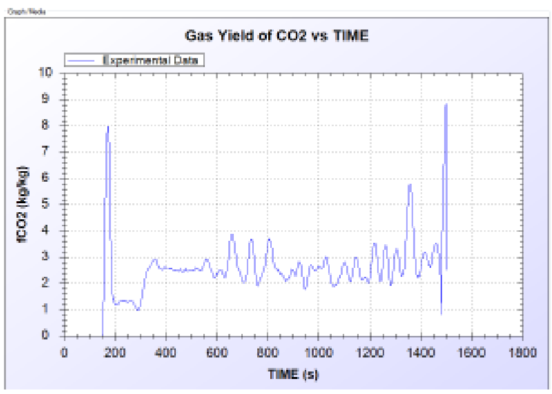


**Figure D.3 UCFIRE Tolerance Comparison**
for Polypropylene Fabric and Dom. ("PPDFS5")
Furn. Foam (Adapted from Hill, 2003)
0.1% of max MLR, 0.1 g threshold
**b) $CO_2$ Yield Profile**

A very different $CO_2$ yield profile results when the threshold is lowered to 0.1% of the maximum mass loss rate. The inclusion of smaller mass loss rates has caused the $CO_2$ yields to reach almost 9 kg/kg near the beginning and end of the test, where mass loss rates are the lowest (maximum possibly is 3.5 kg/kg, refer to Section 5.5). Consequently, although lowering the threshold preserves more of the experimental results, not all of them realistically reflect the actual yields.

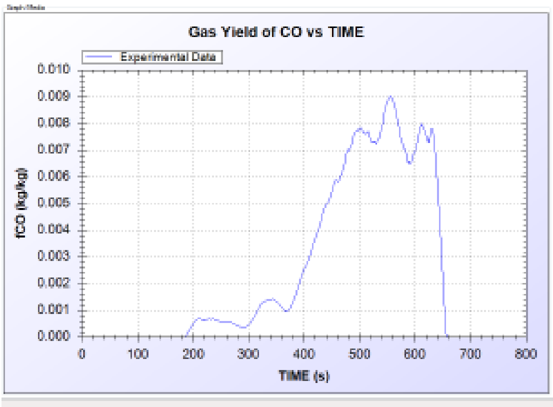


**Figure D.2 UCFIRE Tolerance Comparison**
for Polypropylene Fabric and Dom. ("PPDFS5")
Furn. Foam (Adapted from Hill, 2003)
5% of max MLR, 0.1 g threshold
**c) CO Yield Profile**

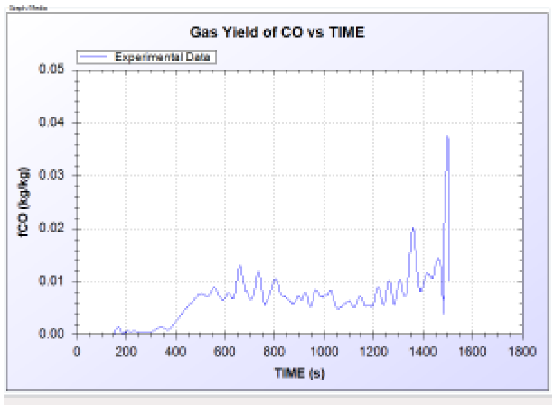


**Figure D.3 UCFIRE Tolerance Comparison**
for Polypropylene Fabric and Dom. ("PPDFS5")
Furn. Foam (Adapted from Hill, 2003)
0.1% of max MLR, 0.1 g threshold
**c) CO Yield Profile**

Similarly from Figures D.2 c) and D.3 c), it can be seen that maximum CO yield has become four times as high when the tolerance level is reduced from 5% (Figure D.2) to 0.1% (Figure D.3). This is most likely due to extremely small mass loss rates than high CO production.

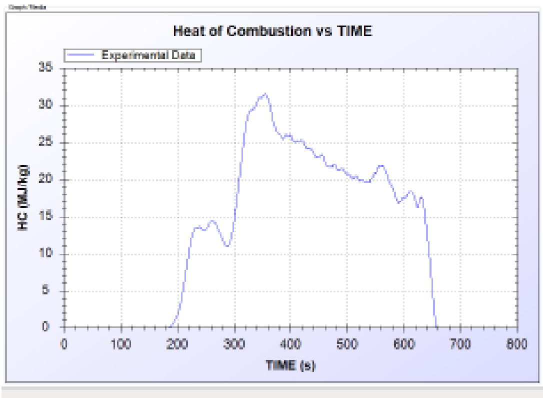


**Figure D.2 UCFIRE Tolerance Comparison**
for Polypropylene Fabric and Dom. ("PPDFS5")
Furn. Foam (Adapted from Hill, 2003)
5% of max MLR, 0.1 g threshold
**d) Heat of Combustion Profile**

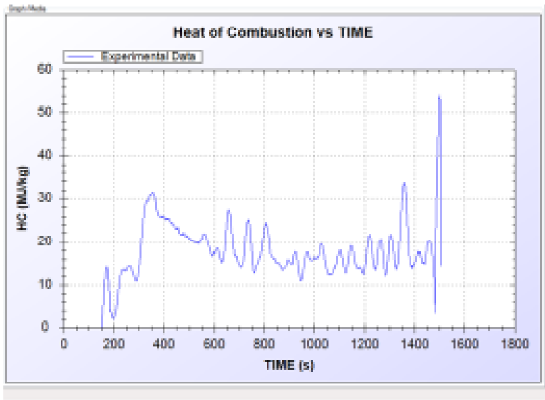


**Figure D.3 UCFIRE Tolerance Comparison**
for Polypropylene Fabric and Dom. ("PPDFS5")
Furn. Foam (Adapted from Hill, 2003)
0.1% of max MLR, 0.1 g threshold
**d) Heat of Combustion Profile**

Spikes in the heat combustion have been observed in Figure D.3 d) when the tolerance is lowered to 0.1%, similar to the rest of the yield profiles (Figures D.3 b), and c) for $CO_2$ yield and CO yield, respectively)

In all cases, both high fluctuations and much higher yields have been observed when the tolerance is lowered from 5% to 0.1% of the maximum mass loss rate. The inclusion of these yield values would affect the final distribution and given unrealistic estimates. Since the cut-off is subjective to the maximum mass loss rate, it was considered that a consistent mass loss rate threshold should be applied to produce comparable results. Section 5.3 discusses the derivation of such threshold, and a final value of 0.005 kg/s was chosen.

For this reason (and others discussed below), UCFIRE was not deemed satisfactory for the purpose of this research. A mass loss rate threshold of 0.005 kg/s has been chosen and used in this research for a typical single seater in a furniture calorimeter tests. This mass loss rate threshold was also adjusted according to the size of the item burned to provide as much consistency in the final results as possible.

A recommended UCFIRE modification would be to allow users the additional option of defining the mass loss rate thresholds as currently adopted by the ASTM and ISO standards for defining the end of a cone calorimeter test.

## *D.2 Invalid Functions*

There were problems with several functions in UCFIRE, one of which occurred when trying to export data to Excel. Error messages appeared when right clicking on the yield of interest for the “Export to Excel” function. Similar situations included trying to fit a polynomial function to the curve (when right clicking on the yield of interest and selecting the “Curve Fitting” function). Polynomials ranging from 1 to 10 were trialled, with similar error messages appearing.

## *D.3 Inconvenient Output Format*

The only output format available was in the form of an XML file, containing both the raw experimental and reduced data in the cells. However, these results could not be readily plotted in Excel as all values were recording in one cell. To plot these graphs outside UCFIRE, some codes must be written to automate the process. Alternatively, applications such as MATLAB had to be used to convert these strings of texts into numbers and transpose them into vertical arrays as these sometimes involve more than 1,000 points.

## *D.4 Unstable Display*

Possibly due to system incompatibility, UCFIRE’s display interface became unstable and displayed results from other tests. Thereafter, UCFIRE ceased to work and was only able to display the same set of test result; despite other test items were chosen. This was only fixed by restarting the application. Similar problem was encountered when loading input files that were not correctly formatted (sometimes simply due to different text alignment styles). The application was not able to debug the fault and simply became inactive, requiring the UCFIRE application to restart.

## *D.5 Recommended UCFIRE Modifications*

UCFIRE is a useful tool for processing and storing fire tests in a meaningful fashion. Once the problems discussed in Section 8.2 are addressed, it can used in other research applications to reduce data in a more mechanistic and efficient manner. Based on the UCFIRE user experience, the following modifications are recommended. Most of the problems encountered are due to version compatibilities (for example, coding is such that it is only applicable for Microsoft Excel 2000, not Microsoft Excel 2003 or later) which does not requires much effort to correct.

### D.5.1 Mass Loss Rate Cut-off Criteria

In UCFIRE's algorithm, all mass loss rates values below the specified tolerance or the threshold value are considered insignificant and will be set to zero. Currently, tolerance is set using the maximum mass loss rate value as the reference point (for example, 5% of the maximum mass loss rate). Extreme limits such as the maximum or minimum values are more variable (refer to Section 8.2.1); therefore, one recommendation would be to use the mean mass loss rate as the reference point instead of the maximum mass loss rate (10% of the mean mass loss rate value instead of 5% of the maximum mass loss rate value).

Another recommended modification would be to include another user-defined mass loss rate threshold, which is also the criteria used in ISO 5660 (1993) to specify the end of test.

### D.5.2 Malfunctioning Functions

During the UCFIRE trial, some malfunctions have been found, causing the error message to occur. These include some display options and exporting the reduced data to Excel spreadsheet, which causes inconvenience as the only output format currently functional is in the XML format, that does not facilitate instant plot generation in Excel for visualisation.