

PROCESSING TUBE FURNACE TEST DATA AND IMPROVING THE DATA REDUCTION ALGORITHMS FOR UCFIRE

Hong H. Tong

Department of Civil & Natural Resources Engineering, University of Canterbury, New Zealand
e-mail: hht23@uclive.ac.nz

Keywords: UCFire, data reduction, XML data structure, mass loss rate, tube furnace, heat release rate.

Abstract. *UCFire is an application for storing and reducing fire test data in a useful manner for fire engineering analysis. Three tasks have been identified to enhance UCFire's functionality and make it a more effective data storage and data reduction tool for fire tests. Firstly, UCFire's existing mass loss rate algorithm is modified such that it is able to consistently obtain realistic gas species yields. Secondly, UCFire's data storage capability is expanded to allow for storage of tube furnace test data. Lastly, the data reduction capability is enhanced whereby heat release rates are automatically computed by UCFire for cone calorimeter test data even when they are unavailable in the exemplar input file. This paper describes in detail the work involved in these three tasks.*

1 INTRODUCTION

UCFire is a database management system developed to store fire test data in a logical and complete manner for subsequent fire engineering analysis [1]. It is based on an eXtensible Markup Language (XML) data structure that allows UCFire to store data in a structured manner, and be easily extensible to store additional types of fire test data. In addition to its data storage capability, UCFire also reduces fire test data in a useful manner. UCFire was initially designed to store and reduce five standard fire test data, namely cone calorimeter tests, furniture calorimeter test, room/corner test, lateral ignition and flame spread test (LIFT), and ignitability apparatus test.

While UCFire possesses some degree of functionality as a fire test database management system, there are areas in which UCFire can be improved upon, so as to enhance the overall attractiveness of UCFire as fire test data storage and reduction tool. Moreover, Hou [2] also attempted to use UCFire to process fire test data, but encountered difficulties in using UCFire to obtain realistic gas species yields.

This paper outlines three tasks that have been carried out to address some of those difficulties, as well as to improve on UCFire's data storage and data reduction capabilities. The three tasks are as follows:

- **Task 1:** To fine-tune UCFire's existing mass loss rate algorithm to enable it to give more realistic gas species yield;
- **Task 2:** To expand the data storage capability of UCFire by enabling it to store and process tube furnace test data in addition to the five standard fire tests;
- **Task 3:** To improve UCFire's data reduction functionality by enabling automatic computation of heat release rate (HRR) data for cone calorimeter tests.

2 LIMITATIONS OF EXISTING UCFIRE APPLICATION

2.1 Existing MLR algorithm

Hou [2] studied the gas species yields and their distribution over different stages of fire, for the combustion of residential furnishing. Hou attempted to use UCFire to mechanically reduce raw test data

collected from cone calorimeter tests and furniture calorimeter tests [3], in order to compute the gas species yield over the burning duration. Equation (1) [4] is adopted in UCFire to compute the gas species yields of a combustion process. y_i is the mass yield of gas species i , X_i is the mole fraction of gas species i , M_i is the molecular weight of gas species i , M_{air} is the molecular weight of incoming and exhaust air, \dot{m}_{duct} is the mass flow rate through the exhaust duct, and \dot{m}_f is the mass loss rate of fuel.

$$y_i = \frac{\dot{m}_{duct} \times X_i \times \frac{M_i}{M_{air}}}{\dot{m}_f} \quad (1)$$

The calculation of gas species yield requires the mass loss rate (MLR), \dot{m}_f , to be determined. One way to estimate the MLR is to scan the mass loss of a burning object over its burning duration, and apply the Savitzky-Golay (SVG) algorithm [5] to filter off noises in mass loss measurements. Staggs [5] had applied the SVG algorithm to three sets of cone calorimeter data, and obtained MLR curves that are superior to those obtained using the numerical differentiation scheme in AS/NZS 3837:1998 [6]. Nonetheless, Tobeck [1] found that the SVG algorithm, when applied to furniture calorimeter test data, could not eliminate the experimental noises due to collapse of burning items near the end of the test. That had resulted in unusual spikes and troughs at the end of MLR curves for furniture calorimeter tests.

Tobeck made modifications to the SVG algorithm [1] to remove these experimental noises and enable it to be applicable to furniture calorimeter tests. One modification involved applying an arbitrary tolerance value to the MLR curve (expressed as a percentage of maximum MLR) to ignore mass loss rates which are below this tolerance level. This tolerance is also referred to as ‘‘MLR cut-off’’ in this paper. In deriving the modified SVG algorithm, Tobeck used a tolerance level of 5% of the maximum MLR, and obtained reasonable MLR profiles. In Hou’s analysis, tolerance levels were varied at 5% and 0.1% of the maximum MLR, and vastly different gas species yield profiles were obtained (see Figure 1). [2]

While lowering the tolerance level preserves more of the test data, setting the tolerance level too low could give unrealistically high gas species yields. With a low tolerance level, extremely small mass loss rates will be included in the MLR curve, resulting in magnified gas species yields calculated using Equation (1).

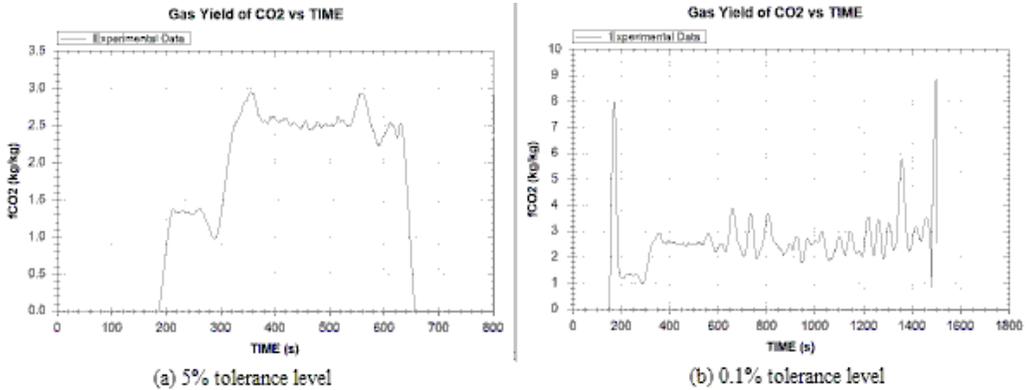


Figure 1: Different carbon dioxide yield profiles obtained using different tolerance levels.

2.2 Selection of additional fire test to be stored by UCFire

UCFire was designed to store fire tests data from five standard fire tests. Given the extensibility of UCFire, other types of fire tests can be incorporated into UCFire to expand its data storage capability.

In this paper, storage of tube furnace test data into UCFire will be discussed. The tube furnace test [7] is a bench-scale test apparatus comprising a tube furnace through which a material sample is driven

through, and air is supplied to the tube furnace chamber to support the burning under different fire conditions. Under these different conditions, gas species concentrations are measured using gas analysers, allowing tenability conditions of different fire conditions to be assessed. Since UCFire can store raw experimental data on measured gas concentrations and reduce these data to obtain gas species yields, enabling storage and processing of tube furnace test data using UCFire is relevant and appropriate.

2.3 Existing methodology for processing heat release rate data in UCFire for cone calorimeter tests

To store heat release rate data in UCFire for cone calorimeter tests, the heat release rate (HRR) or heat release rate per unit area (HRRPUA) data for each experimental scan is pre-calculated manually by the test operator, and inserted into the exemplar input file. The manually-calculated HRR and/or HRRPUA data is then extracted into the XML database using UCFire. Without manually calculating and including the HRR or HRRPUA data into the input file, HRR (or HRRPUA) data will not be stored.

To reduce the need for the test operator to compute the HRR values for cone calorimeter tests prior to storing them using UCFire, this computation can be programmed into UCFire so that it is carried out by UCFire automatically. By enabling automatic data reduction to obtain HRR as well as HRRPUA data for cone calorimeter tests, this adds value to the data reduction functionality of UCFire, and eliminates the need for any test operator to pre-calculate HRR or HRRPUA data prior to storing them. Furthermore, with this functionality, human errors in manual computation of HRR and HRRPUA are also minimised.

3 GENERAL APPROACH AND METHODOLOGY

The general approach for these tasks is to build on the previous UCFire application developed by Tobeck [1]. Microsoft Visual Studio 2010 Professional software is used to edit the programming codes of UCFire. For Task 1, various modifications to the MLR algorithm will be investigated to address the inadequacy of the existing MLR algorithm, and the most appropriate modification to the MLR algorithm will be adopted and made active in UCFire. For Task 2, existing UCFire XML schema file is expanded to allow the storage of test data for tube furnace tests. For Task 3, UCFire's program codes are amended to take into account the absence of any calculated HRR or HRRPUA data in the exemplar input file, and thereafter automatically compute the HRR and HRRPUA data. These automatically-calculated HRR and HRRPUA data will then be stored in the XML database.

4 ADJUSTING THE MASS LOSS RATE ALGORITHM – TASK 1

To improve the estimation of gas species yield by UCFire, the following modifications to the MLR cut-off for the MLR algorithm have been investigated in UCFire:

- Sub-task 1(a): Determine the lowest possible MLR cut-off for the existing MLR algorithm;
- Sub-task 1(b): Set a user-defined MLR cut-off;
- Sub-task 1(c): Set the MLR cut-off relative to the mean MLR rather than maximum MLR;
- Sub-task 1(d): Set the MLR cut-off based on a percentage of the total mass loss;
- Sub-task 1(e): Set the MLR cut-off based on a percentage of the peak or mean HRR.

Gas species yield curves obtained after applying each modification to the MLR algorithm have been studied, using different parameters. Each combination of parameter and modification is considered suitable if the gas species yield curve obtained is assessed to be reasonable after applying the parameter and modification combination. In applying the modifications to the MLR, other than the tolerance level which changes according to each modification, all other default values of the algorithm (i.e threshold value, order of smoothing polynomial, and number of data points to the left and right of the smoothing window of the SVG algorithm) remain similar to what was recommended and adopted by Tobeck [1]. Any changes in the output of the gas species yield can then be attributed strictly to the changes in the tolerance level and not to changes in any other variables of the MLR algorithm.

4.1 Test data used for analysis of Task 1

Three sets of test data are used for investigating the modifications in Task 1, as elaborated below. AS/NZS 3837:1998 [6] and NT Fire 032 [8] are used as the reference test standards for cone calorimeter tests and furniture calorimeter tests respectively.

- Cone calorimeter test data used by Tobeck [1] [named “Cone Test 1”]: This test involved the burning of 100 X 100 X 25 mm polymethyl methacrylate (PMMA) samples under an exposed heat flux of 25 kW/m²;
- Cone calorimeter test data used in ENFE602 Fire Dynamics laboratory experiment [9] [named “Cone Test 2”]: This test involved the burning of 100 X 100 X 12 mm medium density fibreboard (MDF) under exposed heat flux of 30 kW/m²;
- Furniture calorimeter test data used by Tobeck [1] [named “Furniture Test 1”]: This test involved the burning of a single-seater chair with upholstered arms and legs. These chairs were made of radiata pine, polyurethane (PU) and a wool/nylon-based fabric.

4.2 Parameters used for each modification

4.2.1 Sub-task 1(a)

The parameters 0.5%, 1%, 3% and 5% of maximum MLR are arbitrary selected for investigation.

4.2.2 Sub-task 1(b)

In AS/NZS 3837:1998, a mass loss rate per unit area of $\dot{m}''_f = 150 \text{ g/m}^2$ over a 1-min period is used to determine the end of test. For a sample size of 0.01 m², this means that the mass loss over 1-min period has to be less than 1.5 g to indicate an end of test. Assuming that the mass loss is constant over the 1-min period, the MLR is equivalent to 0.025 g/s. Therefore, a user-defined MLR cut-off of 0.025 g/s is investigated for cone calorimeter tests. For Furniture Test 1, NT Fire 032 does not provide a specific criterion for indicating the end of test. Hence, to determine if the parameter $\dot{m}''_f = 150 \text{ g/m}^2$ also applies to furniture calorimeter tests, it is assumed that the mass loss occurred over the base area of the burning chair, which in this case is estimated to be 0.45 m². Therefore, for furniture tests, a user-defined MLR cut-off of 1.125 g/s is investigated.

Another possible user-defined MLR cut-off is based on the accuracy level of the measurement load cell. NT Fire 032 requires measurement load cells to measure the specimen mass with an accuracy of at least $\pm 0.15 \text{ kg}$. If the mass loss over a 1-min period is less than 0.15 kg, it is possible that the noise level from the load cell will overwhelm any measured mass loss over the same period. Assuming that the mass loss is constant over the 1-min period, the MLR is estimated to be 0.0025 kg/s, and this user-defined MLR is also investigated for furniture calorimeter tests. Similarly, AS/NZS 3837:1998 requires the cone calorimeter measurement load cell to have an accuracy of 0.1 g. This suggests that a possible MLR cut-off for cone calorimeter test data can also be 0.00167 g/s, and this user-defined MLR cut-off is also investigated for cone calorimeter tests.

4.2.3 Sub-task 1(c)

The mean MLR is first determined for the main burning segment of the test. Thereafter, parameters 5%, 10%, 15% or 20% of the mean MLR are arbitrary selected and applied as the MLR cut-off.

4.2.4 Sub-task 1(d)

The MLR cut-off is set to be at the points which correspond to “2% and 98%”, “5% and 95%” or “10% and 90%” of the total mass loss from both ends of the MLR curve. These parameters are arbitrary.

4.2.5 Sub-task 1(e)

The MLR cut-off is set to be at the points which correspond to 2%, 3%, or 5% of peak HRR, or 5%, 10%, 15% or 20% of mean HRR from both ends of the MLR curve. These parameters are arbitrary.

4.3 Determining reasonableness of a gas species yield curve

Each proposed parameter and modification combination is applied to the MLR algorithm to obtain carbon monoxide (CO) and/or carbon dioxide (CO₂) yield curves. These curves are then checked against the typical and maximum CO and CO₂ yield values found in literature [10]. The CO and/or CO₂ yield curves will be considered reasonable when they are observed to fall around the range of the typical gas species yields, and do not exceed the maximum theoretical yields.

4.4 Investigation results

Table 1: Summary of results for Task 1.

Sub-task	Tolerance level		Cone calorimeter	Furniture calorimeter
1(a)	$\geq 3\%$ of maximum MLR		OK	OK
	$\leq 1\%$ of maximum MLR		OK	Not OK
1(b)	$\dot{m}_f = (150/60 \times \text{base area of burning object}) \text{ g/s}$		OK	OK
	Based on accuracy of load cell	$\dot{m}_f = 0.0025 \text{ kg/s}$	Not applicable	OK
		$\dot{m}_f = 0.00167 \text{ g/s}$	OK	Not applicable
1(c)	$\geq 10\%$ of mean MLR		OK	OK
	5% of mean MLR		OK	Not OK
1(d)	MLR cut-off at 2% and 98% of mass loss		OK	Not OK
	MLR cut-off at 5% and 95% of mass loss		OK	Not OK
	MLR cut-off at 10% and 90% of mass loss		OK	OK
1(e)	2% of peak HRR		OK	Not OK
	$\geq 3\%$ of peak HRR		OK	OK
	$\leq 15\%$ of mean HRR		OK	Not OK
	20% of mean HRR		OK	OK

Table 1 summarises the investigation results obtained. Reasonable gas species yield can be obtained when any of the above modification is applied on cone calorimeter test data. On the other hand, only some modifications are acceptable for furniture calorimeter test data. To obtain reasonable gas species yield for furniture calorimeter test data, the MLR cut-off can be set to one of the following options below:

- Option (a): MLR cut-off at $\geq 3\%$ of maximum MLR;
- Option (b): User-defined MLR cut-off of $\dot{m}_f \geq (150/60 \times \text{base area of object}) \text{ g/s}$;
- Option (c): User-defined MLR cut-off based on accuracy level of load cell;
- Option (d): MLR cut-off $\geq 10\%$ of mean MLR;
- Option (e): MLR cut-off at 10% and 90% of mass loss;
- Option (f): MLR cut-off $\geq 3\%$ of peak HRR;
- Option (g): MLR cut-off at 20% of mean HRR.

Options (a), (d), (e), (f) and (g) sets a percentile criterion on a pre-determined variable (either peak MLR, mean MLR, mass loss, peak HRR or mean HRR) as a MLR cut-off point, and ignores the MLR data when the MLR falls below this cut off point. Although these parameters seem to give reasonable gas species yield results for one set of furniture calorimeter test data and two sets of cone calorimeter test data, it is uncertain whether the same performance can be achieved for other sets of test data with different materials and burning profiles, which may in turn give a very different predetermined variable. More cone calorimeter and furniture calorimeter test data may be needed to further assess if reasonable gas species yield can be consistently achieved using these options.

Options (b) and (c) are user-defined MLR cut-off points not based on any percentile criterion. For option (b), the base area of the burning object is usually fixed in cone calorimeter tests, but is highly variable across different furniture calorimeter tests. Although this option works well for the size of the object given in Furniture Test 1, this option has not been validated for other sizes of burning objects, and therefore, not recommended for furniture calorimeter test data at this point. Option (b) also works for cone calorimeter tests, but its MLR cut-off value is higher than that determined using option (c), suggesting that more test data is preserved when option (c) is applied to cone calorimeter test data compared to option (b).

4.5 Recommendation for Task 1

Option (c) seems to be the most feasible option to adopt for UCFire. Applying option (c) to obtain gas species yield will not only achieve reasonable gas species yield curves for both cone calorimeter and furniture calorimeter test data, there should also be better consistency in the computed gas species yield results, as these tests will have to adhere to the load cell accuracy requirements stipulated in the respective test standards. Hence, option (c) is programmed into UCFire's MLR algorithm.

5 ENABLE UCFIRE TO PROCESS TUBE FURNACE TEST DATA – TASK 2

5.1 Standard test report requirements

The standard test report requirements for tube furnace tests are obtained from *ISO/TS 19700: Controlled equivalence ratio method for the determination of hazardous components of fire effluents* [7]. These requirements are compared against existing data storage fields in UCFire. The following lists the data fields which are already available in UCFire, and those that are unavailable.

Required data fields that are already available in UCFire include:

- Name and address of testing laboratory;
- Test Identity Number (ID) and test date;
- Test operator;
- Laboratory ambient temperature and humidity;
- Details of test specimen preparation, configuration and conditioning;
- Burning behaviour;
- Mean concentration of each gas species (computed over steady state duration);
- The methods used to determine effluent yields;
- Mandatory test statement;
- Observations and difficulties experienced during testing.

Required data fields that were unavailable in UCFire, and need to be created in UCFire XML schema:

- Decomposition conditions;
- Run temperature;
- Primary and secondary air flow rate;
- Sample drive speed;
- Mass-charge concentration;
- Mass-loss concentration;
- Mean yield of each gas species (computed over steady state duration);
- Mean smoke extinction coefficient (computed over steady state duration);
- Smoke specific extinction area (computed over steady state duration).

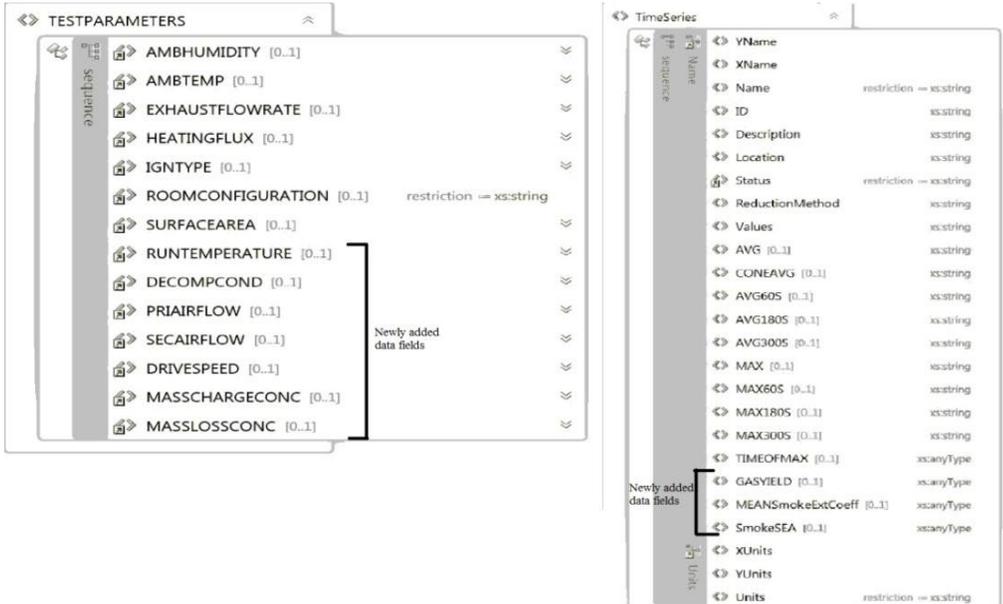


Figure 2: New data fields added to UCFire’s XML schema

Where the XML elements for data storage are unavailable in UCFire, they have been created and added on to the existing UCFire XML schema (see Figure 2). The UCFire application and the exemplar input file are also amended to allow for storage and processing of tube furnace test data. For the newly created data fields, the data for decomposition conditions, run temperature, primary air flow rate, secondary air flow rate, and sample drive speed are extracted directly from the exemplar input file, and the rest are computed by UCFire based on equations found in ISO/TS 19700.

5.2 Test data used for Task 2

Two sets of test data are used for Task 2, as briefly described below. One limitation of these test data is that data on smoke optical density is unavailable. Nevertheless, it is noted that in Cone Test 1, data for smoke extinction coefficient were collected and available. Therefore, these smoke extinction coefficient data are inserted into the input file for Tube furnace test data set 1, and are used to develop the necessary programming codes in UCFire to enable UCFire to process and store mean smoke extinction coefficient and smoke specific extinction area data for tube furnace tests.

- Tube furnace test data set 1 (Test ID: LDPE061208) [named “Tube Test 1”]
This test involved the passing of a low density polyethylene (LDPE) specimen through a tube furnace chamber. The test is conducted under near stoichiometric fire conditions.
- Tube furnace test data set 2 (Test ID: “LDPE061127”) (named “Tube Test 2”)
This test involved the passing of a LDPE specimen through a tube furnace chamber. The test is conducted under well-ventilated fire conditions.

5.3 Determination of steady state period for tube furnace tests

The steady state period for tube furnace tests needs to be established, for the purpose of computing mean gas species yield, mean smoke extinction coefficient and smoke specific extinction area. To do that in UCFire, a dialog box is created to allow the user to key in a start time and end time of the steady state period (see Figure 3). This dialog box will be activated when UCFire detects that a set of tube furnace test data is being processed.

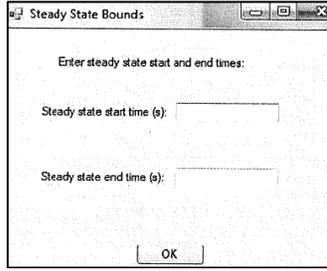


Figure 3: Dialog box to allow user to key in steady state start time and end time.

Once the start time and end time has been keyed in, the times are validated according to the test standard requirements elaborated below. Mean gas species yield, mean smoke extinction coefficient and smoke specific extinction area will be computed if the steady state period is assessed by UCFire to comply with the test standard requirements.

- The steady state period should be at least 5 minutes;
- In that duration, the fluctuation between the maximum and minimum oxygen (O₂) concentration, as well as between the maximum and minimum carbon dioxide (CO₂) concentration, should be less than 20% of the average O₂ and CO₂ concentration in that duration respectively;
- A long term trendline of the O₂ and CO₂ concentration is determined using simple ordinary least squares linear regression analysis [11], and the deviation of this trendline from the average O₂ and CO₂ concentration should be less than 10% of the average O₂ and CO₂ concentration respectively.

5.4 Computation of gas species yield, mean smoke extinction coefficient, and smoke specific extinction area

The mean yield of each gas species (Y_i) is computed by UCFire using Equation (2) and Equation (3). F_v is the measured volume fraction of the component in the chamber. $X_{i,t}$ is the mole fraction of gas species i at time t . M_i is the molecular weight of species i . $V_{m,i}$ is the molar volume of gas i at ambient temperature and pressure. $C_{m,loss}$ is the mass-loss concentration.

$$F_v = \frac{\sum_{t=\text{steady state start time}}^{t=\text{steady state end time}} X_{i,t}}{\text{number of data points between steady state start time and end time}} \times 100 \quad (2)$$

$$Y_i = (M_i / V_{m,i}) \times (F_v / C_{m,loss}) \times 10 \quad (3)$$

The mean smoke extinction coefficient (\bar{k}) is determined from the smoke extinction coefficient test data (k_t) contained in the exemplar input file, using Equation (4). The smoke specific extinction area (σ_f) is determined using Equation (5) [7]:

$$\bar{k} = \frac{\sum_{t=\text{steady state start time}}^{t=\text{steady state end time}} k_t}{\text{number of data points between steady state start and end time}} \quad (4)$$

$$\sigma_f = \frac{\bar{k}}{C_{m,loss}} \quad (5)$$

These computed data are then displayed on UCFire's user interface, as well as stored in the database.

6 ENABLE AUTOMATIC COMPUTATION OF HEAT RELEASE RATE FOR CONE CALORIMETER TEST DATA – TASK 3

To allow UCFire to automatically compute HRR data, \dot{q} , for cone calorimeter tests, Equations (6), (7) and (8) [6] are added into UCFire to compute the HRR values for each scan. $[\Delta h_c/r_o]$ is ratio of net heat of combustion to stoichiometric oxygen/fuel ratio, \dot{m}_{duct} is the mass flow rate through exhaust duct, $X_{O_2}^o$, $X_{CO_2}^o$ are the initial mole fractions of O_2 and CO_2 respectively, X_{O_2} , X_{CO_2} , X_{CO} are the measured mole fraction of O_2 , CO_2 and CO respectively over time, and ϕ is the oxygen depletion factor. Equation (6) is recommended when only oxygen (O_2) analysers are used. When additional gas analysers are used, such as carbon dioxide (CO_2) and carbon monoxide (CO) analysers, Equations (7) and (8) are used. After that, HRRPUA, \dot{q}'' , can be computed by Equation (9).

$$\dot{q} = \left[\frac{\Delta h_c}{r_o} \right] \dot{m}_{duct} (1.10) \frac{(X_{O_2}^o - X_{O_2})}{1.105 - 1.5X_{O_2}} \quad (6)$$

$$\dot{q} = \left[\frac{\Delta h_c}{r_o} \right] \dot{m}_{duct} (1.10) X_{O_2}^o \left[\frac{\phi - 0.172(1 - \phi) \frac{X_{CO}}{X_{CO_2}}}{(1 - \phi) + 1.105\phi} \right] \quad (7)$$

$$\phi = \frac{X_{O_2}^o(1 - X_{CO_2} - X_{CO}) - X_{O_2}(1 - X_{CO_2}^o)}{X_{O_2}^o(1 - X_{CO_2} - X_{CO} - X_{O_2})} \quad (8)$$

$$\dot{q}'' = \dot{q} / (\text{base area of burning object}) \quad (9)$$

Two functions called “HRR_Reduction” and “HRR_Reduction_2” are developed in UCFire to process the test data and calculate the HRR and HRRPUA for every time-step. The algorithm to enable UCFire to perform the computations automatically is as follows:

1. Check that mass flow data through the cone calorimeter duct is present and that both the HRR and HRRPUA data are absent in the exemplar input file.
2. Check the types of gas data or gas analysers available. If only O_2 data is available but not CO or CO_2 , then “HRR_Reduction” function is activated to calculate HRR. If O_2 , CO and CO_2 data are all available, then “HRR_Reduction_2” function is activated to calculate HRR.
3. The HRRPUA will then be calculated.

6.1 Test data used for Task 3

Test data from Cone Test 1 and Cone Test 2 are used to develop the above algorithm and codes. Cone Test 1 contains HRRPUA data, and Cone Test 2 contains HRR data manually-calculated using equations by Janssens [3] where O_2 , CO_2 and CO analysers are available. The pre-calculated HRR or HRRPUA data will first be removed from the respective exemplar input files. UCFire will then attempt to read the exemplar input file and then execute the algorithm accordingly, in order to compute and store HRR and HRRPUA data.

6.2 UCFire-calculated HRR

A comparison of the HRR curve calculated by UCFire using Equation (7) to the HRR curve manually-calculated using equations by Janssens, is depicted in Figure 4. The trend of the UCFire-calculated HRR curve is in line with the trend of the manually-calculated HRR curve. The difference between UCFire-calculated and manually-calculated HRR data is estimated to be around 3%, which is relatively insignificant.

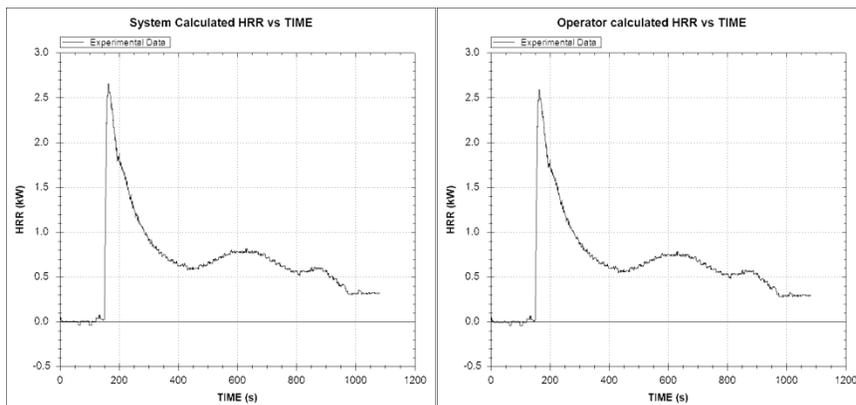


Figure 4: Comparison of heat release rate curves.

7 CONCLUSION

All three tasks were successfully completed, enhancing the data storage and data reduction functionality of UCFire. A reasonable MLR cut-off based on accuracy level of measurement load cells is adopted in UCFire. UCFire is also able to store and process tube furnace test data, and compute HRR data for cone calorimeter tests automatically.

REFERENCES

- [1] D. Tobeck, "Data Structures and Reduction Techniques for Fire Tests", Civil and Natural Resources Engineering, University of Canterbury, 2007.
- [2] J. Y. P. Hou, "Distribution curves for interior furnishings on CO₂, CO, HCN, soot and heat of combustion", Civil and Natural Resources Engineering, University of Canterbury, 2011.
- [3] M. Janssens, "Calorimetry", in *SFPE Handbook of Fire Protection Engineering*, P. J. DiNenno, Ed., 4th ed Quincy, Mass.: National Fire Protection Association, 2008, p. 60.
- [4] D. T. Gottuk and B. Y. Lattimer, "Effect of Combustion Conditions on Species Production", in *SFPE Handbook of Fire Protection Engineering*, P. J. DiNenno, Ed., 4th ed Quincy, Mass.: National Fire Protection Association, 2008, p. 67.
- [5] J. E. J. Staggs, "Savitzky–Golay smoothing and numerical differentiation of cone calorimeter mass data", *Fire Safety Journal*, vol. 40, no. 6, pp. 493-505, 2005.
- [6] Standards New Zealand, "AS/NZS 3837:1998", *Method of test for heat and smoke release rates for materials and products using an oxygen consumption calorimeter*, Standards New Zealand, 1998.
- [7] International Organization for Standards, "ISO/TS 19700:2007", *Controlled equivalence ratio method for the determination of hazardous components of fire effluents*, 1st ed., Geneva: ISO, 2007.
- [8] Nordtest, "NT FIRE 032 (Nordtest method)", *Upholstered furniture: Burning behaviour - Full scale test*, Nordtest, 1991.
- [9] H. H. Tong, "ENFE602 Fire Dynamics laboratory results - Oxygen Depletion Calorimetry", *Unpublished Experimental Results*, University of Canterbury, 2012.
- [10] B. Karlsson and J. G. Quintiere, "Combustion Products", in *Enclosure fire dynamics*, USA: CRC Press, 2000, pp. 227-254.
- [11] T. A. Reddy, "Estimation of Linear Model Parameters Using Least Squares", *Applied Data Analysis and Modeling for Energy Engineers and Scientists*, Springer, 2011, p. 141.