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# Modelling pyrolysis of charring materials: determining flame heat flux using bench-scale experiments of medium density fibreboard (MDF)

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## HIGHLIGHTS

- Mass loss rate and total incident heat flux has linear correlation.
- We measured the total incident heat flux caused by flame and cone.
- The extra heat flux led by flame is found to be increasing with heat release rate.

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## ABSTRACT

Medium density fibreboard is a homogenous wood product which is a suitable candidate for validating the pyrolysis model of charring materials. For comparison between model and experiment, this article presents the burning behaviour of MDF under cone calorimeter with different experimental conditions. The total incident heat flux, as a significant boundary condition for pyrolysis modelling, is specifically studied both experimentally and theoretically. The experimental conditions were found to have no significant impact on the ignition phase however the sample thickness would lead to different burning behaviours. The total incident heat flux led by cone and flame at sample surface was experimentally measured and the experimental results were evaluated using non-flaming experiments with inert gas. An analytical model based on classical ignition theory is developed to address the mechanism of mass loss caused by incident heat flux, involving the effects of char layer and back boundary. The model shows that the mass loss rate correlates linearly with the total incident heat flux for a specific char layer thickness and back boundary condition. The model was validated for the non-flaming and flaming experiments to further justify the reliability of heat flux measurements. An empirical equation describing the flame heat flux is proposed.

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## 1. Introduction

Features of engineered wood product make it a compatible solution for the recent energy and resources crisis (Lee et al., 2011). Besides, owning to recent national policies and increased interest in health care, conventional chemical engineered products are being replaced by environmentally friendly engineered wood products, such as low formaldehyde emission medium density fibreboard (MDF) (Gupta, 2007). As a result, the demand of modern society on engineered wood products has significantly increased. Consequently, the concerns of engineered wood products as hazardous and risky materials while burning have also increased as these materials might become a significant contributor of heat and toxic species during pyrolysis and combustion (Jiang et al., 2010). To develop appropriate safety strategy, the burning behaviours of engineered wood products have to be investigated in depth, both experimentally and theoretically. In this research, MDF investigated is an engineered wood product formed by breaking down wood residuals into fibres and fusing these fibres with wax and resin. The MDF panels are manufactured under high temperature and pressure onto the raw mats made out of the mixture of fibres and additives.

The burning behaviours of materials have been investigated using different bench-scale experiments such as the cone calorimeter (Tsai, 2009; Spearpoint and Quintiere, 2000), the Fire

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Propagation Apparatus (Chaos et al., 2011) and the Panel Radiator (Dai et al., 2013). The literature reports significant amount of experimental results from cone calorimeter for natural wood or biomass materials (Boonmee and Quintiere, 2002; Rhodes and Quintiere, 1996; Delichatsios and Paroz, 2003; Harada, 2001; Babrauskas and Parker, 1987). However, very little information has been published for engineered wood products, especially MDF. The existing researches (Di Blasi, 1996; Hagge and Bryden, 2002; Rein et al., 2006; Lautenberger et al., 2006; Lautenberger and Fernandez-Pello, 2012) have also shown that there is insufficient information for the validation of pyrolysis model for charring materials. Validating the pyrolysis models of charring materials such as wood has been challenging due to the anisotropic nature of wood where the thermophysical and kinetic properties vary with grain direction. Parameters such as thermophysical and kinetics properties have been specified based on the values from the literature for different wood species, which lead to uncertainties in the modelling results. Genetic algorithms (Rein et al., 2006; Lautenberger et al., 2006; Lautenberger and Fernandez-Pello, 2012) have been applied to obtain optimised model inputs based on decomposition or multi-scale experimental data to improve model comparison with experiments. However, these comparisons are mathematically fitted rather than based on physical material properties determined experimentally.

On the other hand, MDF is a relatively homogenous material which is a suitable candidate for validating the pyrolysis model of charring materials. Therefore this article specifically presents the burning behaviours of MDF in bench-scale combustion experiments while the thermophysical and kinetics properties were presented elsewhere in the literature (Li et al., 2013a, 2013b, 2014). These experimental data will be used to validate a developed pyrolysis model while the measured irradiances will be used as the boundary conditions in modelling. The current work is part of a wider scope of research on developing a comprehensive pyrolysis model for charring materials where the objective is to produce a developed model or methodology which is applicable to a wide range of experimental conditions.

## 2. Experiments

### 2.1. Bench-scale cone calorimeter

In this study, the experiments were performed using a cone calorimeter manufactured by Fire Testing Technology Ltd. in accordance with ISO 5660-1 (IS0, 1993). Four sets of cone experiments were carried out in the current study, as shown in Table 1. The first set experiments used a specific holder made of kaowool to insulate the sample which provides a one-dimensional heat transfer condition while in the second set experiments the sides of the samples were fully exposed to evaluate the effect of boundary conditions. As flame will lead to extra irradiance to the sample, the flame incident heat flux ought to be determined. Thus in the third set experiments a heat flux gauge was used to measure the heat flux irradiating to the sample surface. The fourth set experiments were conducted in a sealed chamber which allows nitrogen filling up during the experiment process. In such a case, the experiments will end up with no flame due to the inert gas, so called “non-flaming experiments”. Fig. 1 presents the cone calorimeter as well as its modified versions with the corresponding sample holders for the different sets of experiments. From Fig. 1(b), the sample mass was not recorded as the load cell was replaced by the support frame and water cool system for the heat flux gauge of measuring flame heat flux. In the non-flaming experiments, a nitrogen chamber made of strain steel was used to generate an inert atmosphere where the nitrogen entered the chamber at a rate of 30 L/min through a regulator, as shown in Fig. 1(c).

From Fig. 1(a), the sample holder in the second set experiments is made of high density calcium silicate board. From Fig. 1(b), in the third set experiments a 6 mm hole was drilled through the centers of the holder and the sample to position the heat flux gauge. The used heat flux gauge is Schmidt-Boelter type whose front surface is painted with replaceable black suede and its diameter is 5 mm. The measurement range of heat flux gauge is 0 to 150 kW/m$^2$. In Fig. 1(c), the sample back in the non-flaming experiments was exposed to the environment using an opened kaowool holder while the sides were still insulated. This configuration is set up to simulate the MDF panels in a flashover compartment. The duration for non-flaming experiments was 900 s due to the limitation of nitrogen supply. The cone experiments with different conditions are summarized in Table 1. Three cone heat fluxes: 35, 50 and 65 kW/m$^2$ have been used in the experiments. Each experiment in Table 1 will be repeated at least once to evaluate the repeatability.

### 2.2. Sampling process

The current study involves two MDF panels made by a local manufacturer with thicknesses of 25 mm and 18 mm. The bulk

**Table 1**
Experimental setup in cone calorimeter experiments.

| Experiment | Sample thickness (mm) | Set | Cone heat flux (kW/m$^2$) | Backing | Flaming/Nonflaming | Parameters measured |
|---|---|---|---|---|---|---|
| 1 | 18 | 1 | 35 | Insulated | Flaming | Mass loss, HRR |
| 2 | | | 50 | Insulated | Flaming | Mass loss, HRR |
| 3 | | | 65 | Insulated | Flaming | Mass loss, HRR |
| 4 | | 2 | 35 | Insulated | Flaming | Mass loss, HRR |
| 5 | | | 50 | Insulated | Flaming | Mass loss, HRR |
| 6 | 25 | 1 | 35 | Insulated | Flaming | Mass loss, HRR |
| 7 | | | 50 | Insulated | Flaming | Mass loss, HRR |
| 8 | | | 65 | Insulated | Flaming | Mass loss, HRR |
| 9 | | 2 | 35 | Insulated | Flaming | Mass loss, HRR |
| 10 | | | 50 | Insulated | Flaming | Mass loss, HRR |
| 11 | 18 | 3 | 35 | Insulated | Flaming | HRR, Incident heat flux |
| 12 | | | 50 | Insulated | Flaming | HRR, Incident heat flux |
| 13 | | | 65 | Insulated | Flaming | HRR, Incident heat flux |
| 14 | 25 | 3 | 35 | Insulated | Flaming | HRR, Incident heat flux |
| 15 | | | 50 | Insulated | Flaming | HRR, Incident heat flux |
| 16 | | | 65 | Insulated | Flaming | HRR, Incident heat flux |
| 17 | 18 | 4 | 35 | Exposed | Nonflaming | Mass loss |
| 18 | | | 50 | Exposed | Nonflaming | Mass loss |
| 19 | | | 65 | Exposed | Nonflaming | Mass loss |

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