Review on heat release rate of burning furniture

W.K. Chow
Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

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ABSTRACT

Aspects on furniture fires are discussed. Results on the heat release rates on burning reported in the literature are reviewed. These included the recent big project on studying Combustion Behaviour of Upholstered Furniture (CBUF) in Europe. These data are useful for working out a design fire in buildings of different uses. Important phenomena such as the possibility to flashover can be assessed.

1. INTRODUCTION

Past fire record indicated that burning a furniture, particularly a sofa or cushion foam, was the main cause of accidental fires. Several such cases happened in Hong Kong before [e.g. 1]. Heat released might be strong enough to ignite adjacent items such as wood partition walls, floor coverings and other furniture which are not easy to ignite by electric sparks or cigarettes. This point should be taken note of, particularly for public entertainment places like those karaokes with partition walls made of timber product [2,3]. It is important to understand the heat release rates of burning furniture foam and their contributions to a compartment fire at the preflashover stage [e.g. 4,5]. Reviewing this becomes the objective of this paper.

As listed in NFPA-92B [6], burning upholstered furniture, stacked furniture near combustible lining and non-fire retarded plastic foam storage might give an ultra-fast t^2-fire. Burning horizontally distributed office furniture would give a medium t^2-fire. There might be an incubation period for all cases. But there are always arguments among the Authorities and the designers on taking which 'cut-off' value as the design fire.

Upholstered furniture is quite complicated with several fuel elements including cover fabric, seat cushion material and the padding. How these fuels would burn depends on the material composition, thickness and density [e.g. 7]. There have been extensive studies on upholstered furniture over the past 10 years [e.g. 7-14]. One of the recent biggest projects is perhaps the project on Combustion Behaviour of Upholstered Furniture (CBUF) in Europe [12-14].

Before working out regulations to specify 'fire safe' furniture [e.g. 15,16], the burning behaviour of common furniture and their constituting materials should be studied. Although it is expensive to carry out full-scale burning tests, such an experimental facility [17] is now available under local control. This was built at remote area in China due to the space constraints and environmental protection policy in Hong Kong.

2. REVIEW ON FURNITURE MATERIALS

Typical heat release rate curves for foam and fabrics measured from the recent CBUF project [12-14] are shown in Figs. 1 and 2.

Selected materials for furniture are:

- Padding
    - FR cotton batting
    - Polyurethane foam (fire-rated FR or non fire-rated NFR)
    - Foam, cotton, polyester
    - CMHR/Melamine or PU foam
    - Neoprene
    - PS beads
    - Latex foam

    Typical heat release rates of different foams are shown in Fig. 1.

- Fabrics
    - Leather
    - PVC
    - PU
    - Polyolefin
    - Cotton/linen/rayon
    - Nylon/olefin
    - Blend

Typical heat release rates of different fabrics over high resilient urethane foam are shown in Fig. 2.

- Frame

  - Wood product
  - Polypropylene
  - Polyurethane
  - Metal/non-combustible
  - Structural foam (charring)

3. HEAT RELEASE RATES

One of the earliest systematic studies on furniture fires was perhaps due to Babrauskas and Walton [9]. Based on the results from a furniture calorimeter, the heat release rate of a single item of burning furniture can be described by a curve of triangular shape determined by the peak heat release rate Q_p (in kW); time to the peak Q_p t_p (in s); triangular base width t_{bw} (in s); and time to start of base t_s (in s) as shown in Fig. 3.

Q_p (in kW) can be modelled by generic materials identification with values assigned for different fabric, padding, frame, mass and style of the furniture; or based on bench-scale measurement with Q_p given in terms of the rate of heat release rate per unit area $\overline{Q}_{BT}$ (in kWm^{-2}) in bench-scale test by:

$$Q_p = 0.63\,\overline{Q}_{BT}\,\alpha_{mass}\cdot\alpha_{frame}\cdot\alpha_{style} \qquad (1)$$

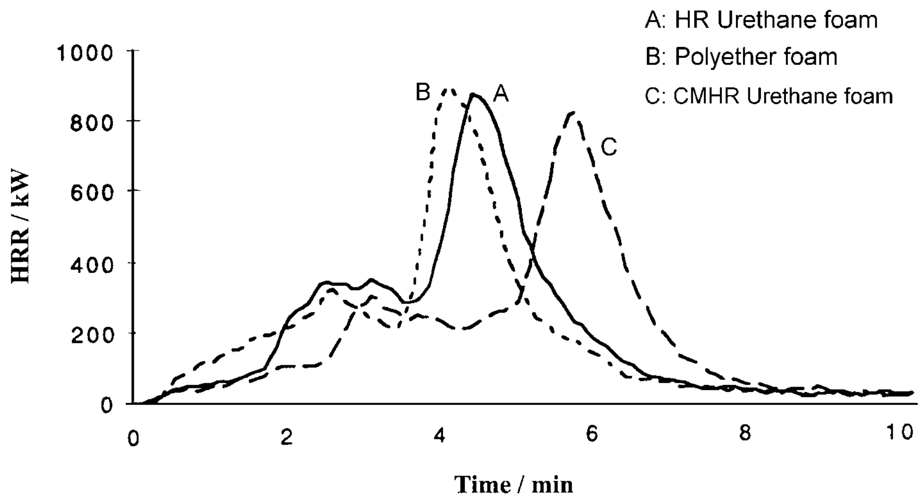


Fig. 1: Heat release rate of different foams (Sundström 1995)

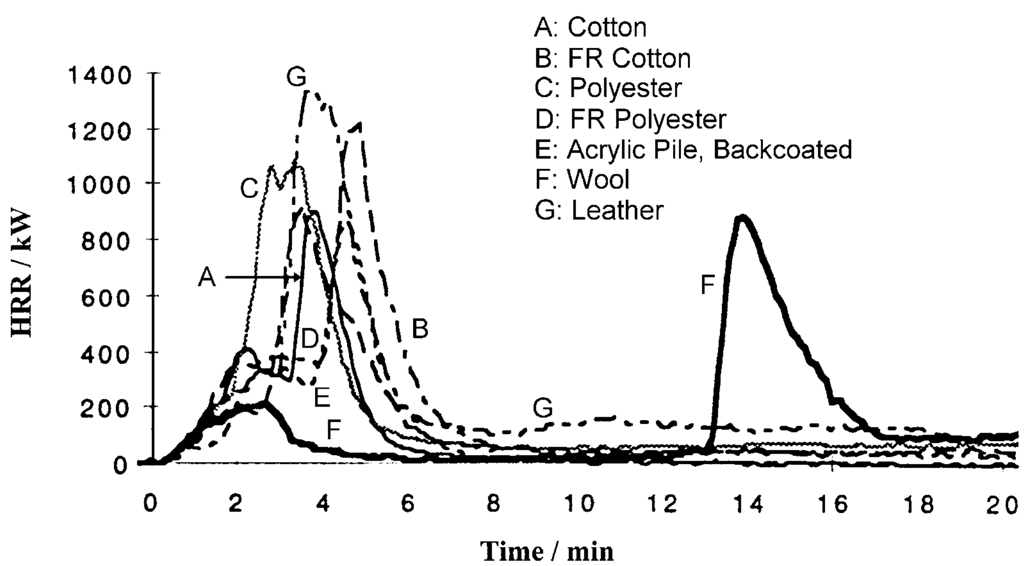


Fig. 2: Heat release rate of different fabrics over high resilient urethane foam (Sundström 1995)

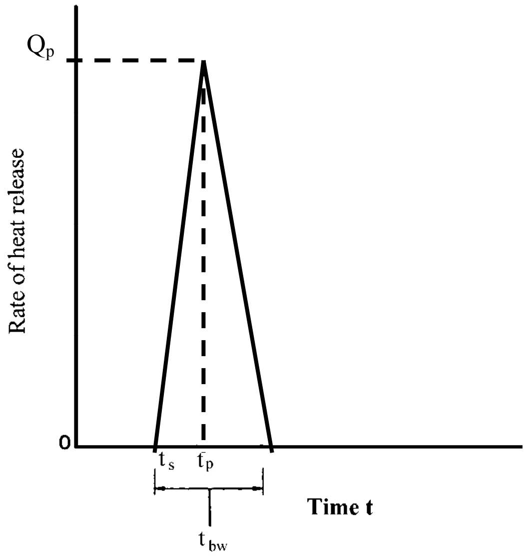


Fig. 3: Heat release curve for upholstered furniture

When using a cone calorimeter, the radiative heat flux is 25 kWm^{-2}, and $\overline{Q}_{BT}$ is determined over an averaging period of 180 s after ignition [e.g. 10]. The other factors are the mass factor α_{mass}, the frame factor α_{frame} and the style factor α_{style}. Recommended values are reviewed in the literature and would not be reported here.

The average rate of heat release per unit area $\overline{Q}_{BT}$ for N components of the furniture, such as the lining fabric, padding materials and frame, can be estimated by their transient heat release rate per unit area $Q_{fab}(t)$, $Q_{pad}(t)$ and $Q_{frame}(t)$ measured by the cone calorimeter. Transient $Q_{BT}(t)$ can be estimated by including all heat contributions by the addition rule, neglecting the burning effects of other materials.

$$Q_{BT}(t) = Q_{fab}(t) + Q_{pad}(t) + Q_{frame}(t) \quad (2)$$

Integrating from the ignition time t_i (in s) to 180 s gives an average:

$$\overline{Q}_{BT}(t) = \frac{1}{180}\int_{t_i}^{t_i+180} Q_{BT}(t)\cdot dt \quad (3)$$

As quoted by Babrauskas [10], the data for $\overline{Q}_{BT}$ over 180 s are higher than 280 kWm^{-2} for ordinary PU, less than 280 kWm^{-2} for melamine PU, less than 60 kWm^{-2} for American Combustion Modified High Resilience (CMHR) PU foam, less than 85 kWm^{-2} for hydrophilic PU, and less than 45 kWm^{-2} for neoprene.

t_{bw} (in s) is given in terms of the mass of combustible item m (in kg) and the effective heat of combustion Δh_c (in $kJkg^{-1}$) by:

$$t_{bw} = \frac{C_3 m \Delta h_c}{Q_P} \quad (4)$$

Note that C_3 is an empirical factor equal to 1.3 forwood frame and 1.8 for metal or plastic frame.

4. THE CBUF PROJECT

At least four types of furniture can be observed in the CBUF project [12-14]:

- Quick development with high peak heat release rate.
- Delayed development, moderate peak heat release rate.
- Slow development, low peak heat release rate.
- Very limited burning.

Typical results of the heat release rate curves are shown in Fig. 4.

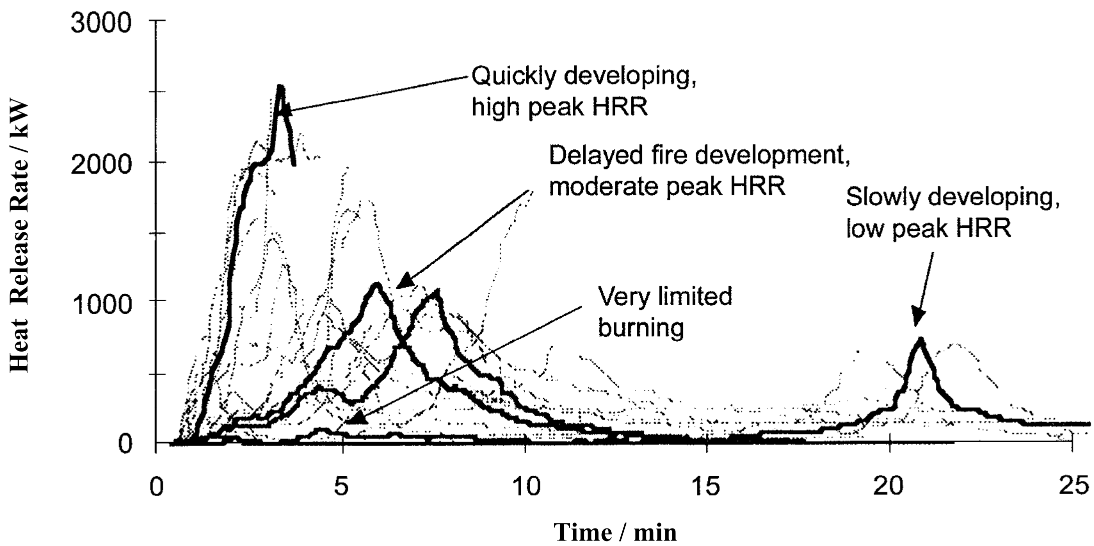


Fig. 4: CBUF results on European furniture (Sundström 1995)

With the heat release rate curve identified, a fire model can be used for predicting the probable fire environment. For instance, the smoke layer is a measure of tenability which can be predicted accurately by a fire zone model once the heat release rate is known. That is why the heat release rate curves are so important.

Further, it was found that the heat release rate of upholstered furniture can be predicted by testing the composite samples in a cone calorimeter with three models:

- Model I

  Based on statistically-correlated factors for predicting the heat release rate of the burning item, the peak heat release rate and the time to attain that are predicted.

- Model II

  Based on the burning area-convolution technique, the heat release rate per unit area $q_c(t)$ of the composite samples in a furniture can be measured by a cone calorimeter, and heat release rate of the furniture Q_{furn} can be calculated by the possible increase rate of burning area $A'_{furn}(t)$:

$$Q_{furn} = \int_0^t q_c(t-\tau)A'_{furn}(\tau)d\tau \qquad (5)$$

  Note that $q_c(t)$ is measured for the sample of thickness 50 mm under a radiative heat flux of 35 kWm^{-2}. The effective burning area $A_{furn}(t)$ is in fact not a physical area but a correlation function relating the heat release rate measured in a furniture calorimeter to the heat release rate per unit area measured in a cone calorimeter. In the CUBF project, A(t) is given by:

$$A(t) = A_{max}\,\alpha\,(\theta) \qquad (6)$$

  where A_{max} is the maximum burning area, t_{max} is the time to reach the maximum burning area, and α is a dimensionless function expressed in terms of the dimensionless time θ as:

$$\theta = \frac{t}{t_{max}} \qquad (7)$$

  Typical results for armchairs are shown in Fig. 5.

Further, as reviewed by Höglauder and Sundström [14], two types of functions are identified: domestic and contract (public). The heat release rate Q_{furn} (in kW) can be expressed in terms of time t (in minutes) as:

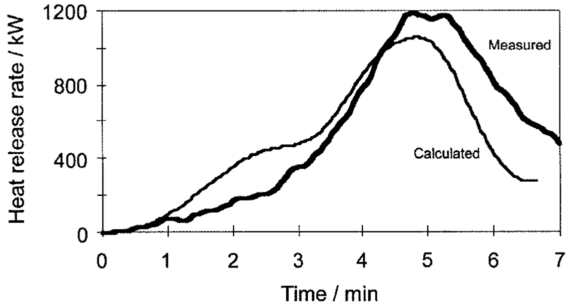
- Domestic upholstered furniture

$$Q_{furn} = 2500 \exp[-0.4\,(t-3)^2] \qquad (8)$$

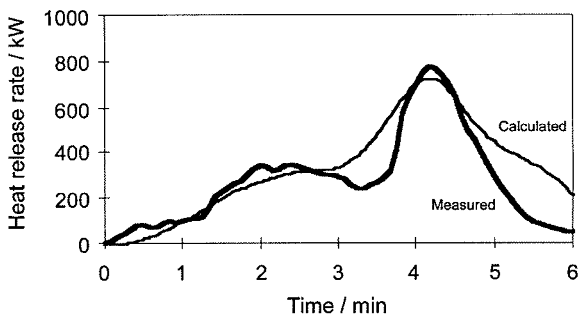
- Contract (public) upholstered furniture

$$Q_{furn} = 1500 \exp[-0.2\,(t-4)^2] \qquad (9)$$

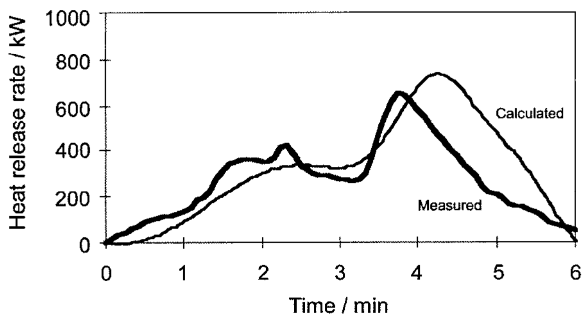
Results are compared with ISO 13388 [18] and NKB 1994:07 [19] in Fig. 6.



(a) Item A



(b) Item B



(c) Item C

Fig. 5: Measured and predicted heat release rates for armchairs from convolution model (Höglander and Sundström 1997)

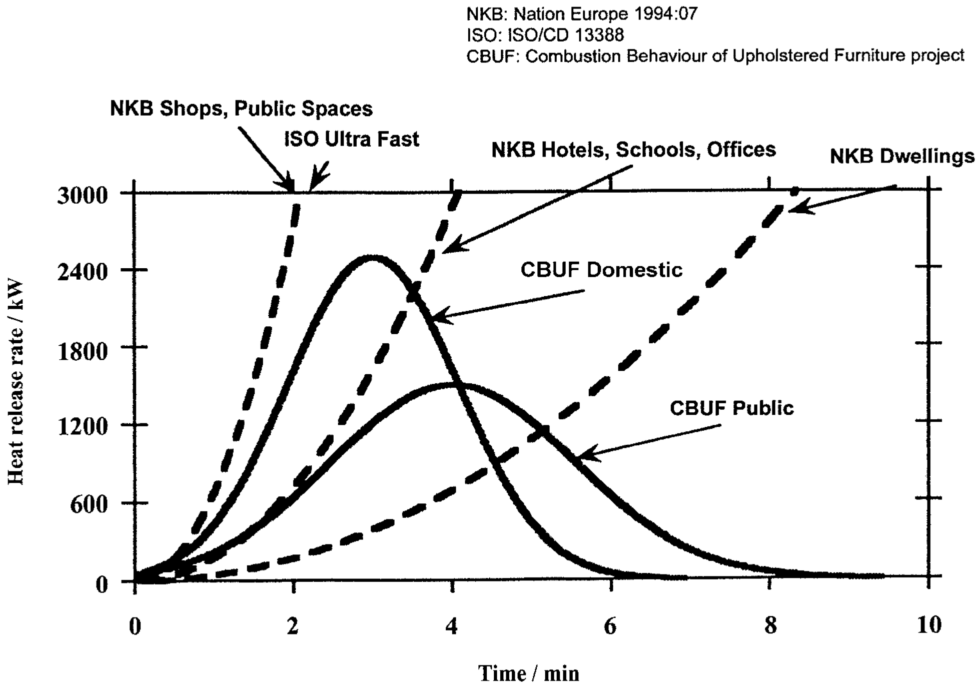


Fig. 6: Design fires for public and domestic type upholstered furniture (Höglander and Sundström 1997)

5. CONCLUSION

In this paper, studies on fire behaviour of furniture, especially the heat release rates, were briefly reviewed as there are lots of works reported in the literature. The study is useful for the authorities [15,16,20,21] to set up some guidelines on providing 'fire safe' furniture. Existing experience such as the CBUF [12-14] project as described briefly in above should be referred to. It is no good just to specify something [e.g. 15,16] without support from in-depth studies in this new century.

Results on the full-scale burning tests, particularly the furniture calorimeter, must be included in the local regulations. It is obvious that a database on fire behaviour for local materials should be developed from those full-scale burning tests. Correlation relations with the bench-scale tests should also be derived [e.g. 22,23] so that the cost for assessing new products would not be too high.

As reported in the literature, results measured from a cone calorimeter [e.g. 4,8,24,25] is also useful particularly in understanding the fire behaviour, both heat and smoke aspect of the materials including sandwich panel [26]. The fire aspects for local furniture has been studied with a cone calorimeter [e.g. 4,8,24,25] and will be report later. Fire aspects of materials samples for all local furniture should then be assessed also by a cone calorimeter. Important parameters useful for the Authority to set up regulations for assessing the propensity to flashover [27] and total heat release rate are recommended to be identified. Arbitrary scale as proposed by Petrella [24] is a good starting point for drafting the codes, in complement with full-scale burning tests on local materials.

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