NECESSITY OF CARRYING OUT FULL-SCALE BURNING TESTS FOR POST-FLASHOVER RETAIL SHOP FIRES

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ABSTRACT

High combustible contents are stored in small retail shops including those located in crowded shopping malls. As the number of non-accidental fires appeared to be increasing, the general public is now quite concerned about the hidden fire hazard. For assessing the consequences of a fire, the possible heat release rates should be studied experimentally. Not only that, conducting full-scale burning tests for local retail shops under flashover conditions is necessary and had been carried out recently.

In this paper, the resultant heat release rates by burning those combustibles in a shop fire after flashover will be reported. Experimental data on heat release rate, oxygen concentration, temperature and radiative heat flux are presented. Whether the heat release rate can be reduced by discharging water mists will also be investigated.

1. INTRODUCTION

Because of the high land price, most of the retail shops in Hong Kong are small and packed with combustibles [e.g. 1,2], such as shops selling personal computers, video compact disks, toys and cartoons in shopping malls. The total amount of combustibles stored in a shop can be quantified by the fire load density FLD (in MJm^{-2}), i.e. the total heat generated for burning all items per floor area. The upper limit of FLD under local codes [3] is 1135 MJm^{-2}. Fire safety in these small retail shops should be considered carefully, especially for those in terminals and public transport interchanges where the passenger loading is extremely high during rush hours [4]. For hazard assessment, the heat release rate (in MW) has to be known [e.g. 5,6] and this quantity is very different from FLD which would give the maximum amount of heat released (in J) upon burning up all the combustibles. But this would happen only when there is adequate ventilation and high enough temperature.

The 'design fire scenario' [7] is one of the primary uncertainties in fire safety engineering. A design fire depends on the use of the building and the materials used and stored, therefore it cannot be decided without understanding the combustibles present. The heat release rate [e.g. 5,6] has to be known and results can be used as input parameters for fire models in studying fire environment. Values used for different local application [e.g. 1] were up to 7 MW for terminal halls; 5 MW for shopping malls; and up to 7 MW for atriums. It is difficult to decide the value as there is no database for local combustibles. It appears that the number of fires not due to accident is increasing in the past few years as observed in karaokes, discos, World Trade Centre [8] and the recent underground railway fire in Korea [9]. Whether the fire safety provisions are for protection against accidental fire, arson fire, terrorist attack fire or mass fire due to big disasters such as earthquakes or explosion of big gas tanks have to be clarified [8]. Anyway, rigs similar to an 'industry calorimeter' in Sweden [e.g. 10] should be developed to burn an actual retail shop for studying how much heat would be released. This is expensive but necessary, and the concept is pointed out in this paper.

There were some data on total heat release rates for burning combustibles in retail shops, libraries and stores. For example, design fires deduced from large-scale fire tests in a sprinklered calorimeter were reported [5]. But these tests were started from a small fire such as an 'igniter' due to a short-circuited electrical appliance, a litter bin, or a gas burner as used in some standard fire tests. There is no radiation heat flux applied to test the samples as in a cone calorimeter. Results are useful for understanding how a fire grows, develops to flashover and then spreads to adjacent areas. But this will not give the contribution of materials, nor their assemblies, to a fire under flashover condition. The heat release rate measured would not be too high as only a small amount of the combustibles were ignited. And for most cases, fire suppression systems might be operated to reduce the resultant heat release rate. The tests then become a demonstration on how the system would act at the tested fire, but not for understanding the actual heat release rate and the possibility of igniting the combustibles under flashover condition. The situation should be reviewed as more fires other than due to accidents were reported.

Effect of high thermal radiation heat flux (such as 20 kWm^{-2} for flashover) on combustibles in a shop should be included in studying the possible heat release rate. Missing this point might be quite serious for retail shops. Combustible items stored there such as plastic dolls, especially those without quality control through standard fire tests, might be ignited easily by the incident heat flux if there is an accidental fire. Note that flashover would occur easily in such small retail shops as raised before [2]. Upon ignition of those combustibles, much larger quantity of heat and smoke would be liberated and spread to the hall space outside the shop. What will happen if the big hall is overcrowded?

Better understanding on the probable heat release rate under flashover is strongly recommended. Preliminary burning tests of several fire scenarios in small retail shops under flashover condition were performed in a new full-scale burning facility, the PolyU/HEU Assembly Calorimeter [11]. That facility was just developed as a collaboration project between the Harbin Engineering University (HEU) and The Hong Kong Polytechnic University (PolyU). Results on heat release rate in flashover shop fires will be reported in this paper.

2. COMBUSTIBLES IN A SMALL RETAIL SHOP

For local small retail areas [1,2], combustibles include plastic toys in blister packs stored in vertical stacks; paper boxes and hanging arms; soft toys, pillows on wire display baskets; video cassettes and CD displays; sweets and candies with plastic bags; and sports wares, jackets on plastic hangers with plastic bags for keeping out the dust.

But for those small retail shops located in terminal halls or public transport interchanges, only selected combustibles are allowed to store. Examples are newspapers and magazines; cigarettes and tobacco; alcohols up to 75 ℓ; shoes, not selling, but repairing and polishing; clothing in cleaning collection points; furniture including polyurethane foam sofas or cushions; coffee tables with wood or other timber products and chairs. Flame spreading of building materials used would be controlled. Fibreglass composites and flammable aerosols are usually not allowed.

The likelihood of flashover in the shop had been pointed out with points of concern identified:

- Consequences of flashover [e.g. 12] in a shop should be watched. The heat release rates of combustibles stored in the shop are key factors [13]. Storing products of heat release rate higher than the value giving flashover under a certain ventilation condition should be watched carefully.
- Effectiveness of operating sprinkler system in controlling a fire should be watched and water mist system [e.g. 14] might be used if necessary.
- Fire safety management schemes [e.g. 15] including training of the store-keepers and the building management staff are to be worked out carefully. For example, keeping a fire to be smaller than the design fires for sizing the sprinkler and smoke extraction systems should be ensured.

All points should be analyzed carefully to provide total fire safety. Performing full-scale burning tests on some selected shops is necessary to observe key fire issues. Performance of fire safety provisions such as water mist fire suppression system on those shops in big halls [16] can also be demonstrated. Consequences of flashover fires for some dangerous arrangements of concern must be studied. It is difficult to work out fire safety regulations and recommend good fire safety management without in-depth studies on fire dynamics.

3. PRELIMINARY FULL-SCALE BURNING TESTS

A set of preliminary full-scale burning tests were carried out to study the heat release rates resulted from burning combustible items in small retail shops. These were measured in the PolyU/HEU Assembly Calorimeter [11] located in Lanxi, a remote area in Harbin, Heilongjiang, China. An exhaust hood with a fan-duct system was developed for measuring heat release rate using the oxygen consumption method [e.g. 5].

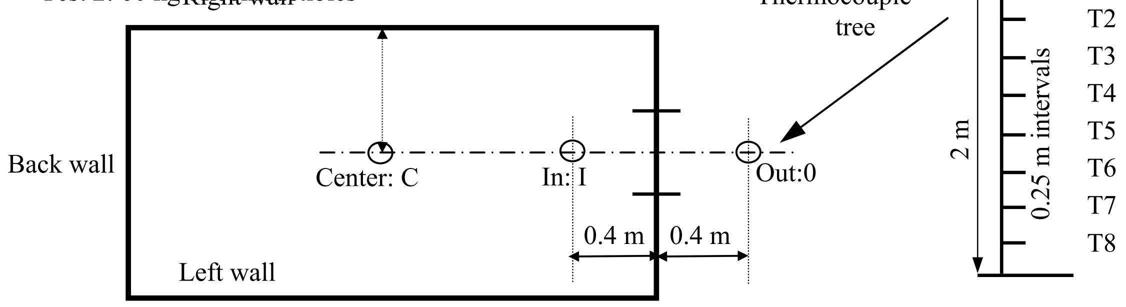
Three fire scenarios were tested for newsstands with books and newspapers arranged in a room of length 3.6 m, width 2.4 m and height 2.4 m with a door of height 2 m and width 0.8 m as in Fig. 1 under flashover condition. Flashover was set off by burning sufficient amount of gasoline. That is similar to testing materials by a cone calorimeter [e.g. 5] where the samples are exposed under a radiative heat flux of values varying about 20 kWm^{-2}.

- Test 1: 15 kg of combustibles

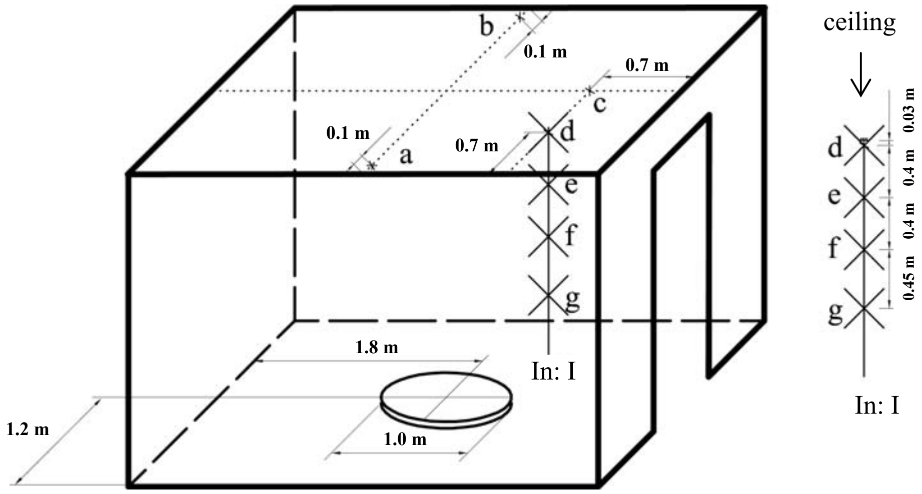
  Book displays of width 1 m and height 2.2 m were put at the left and back walls of the room. Mass of the books, magazines and newspapers was 15 kg. Gasoline of 2000 ml was placed in a pool of diameter 0.5 m to get flashover. Thermocouples T1 to T8 were placed at points in centre C, inside and outside of the shop I and O as in Fig. 1.

- Test 2: 60 kg of combustibles

  Books, magazines and newspapers of 60 kg with bigger displays of 2 m width and 2.2 m height were placed at the back and the right walls. A bigger pool of 1 m diameter and 15000 ml of gasoline was used to give a flashover fire. Locations of thermocouples were the same as test 1. The books and magazines were ignited spontaneously by the heat flux due to the flashover fire.



(a) Arrangement for tests 1 and 2



(b) Arrangement for test 3

(c) Layout of combustibles

Fig. 1: Testing configurations

- Test 3: 90 kg of combustibles

  The back, left and right walls of the room were placed with books on display boards of width 2 m and height 2.2 m. A total amount of 90 kg of books, magazines and newspapers was used. Of which, 15 kg of newspapers was placed on the floor. A pool fire of 1 m diameter with 3000 ml gasoline was used to set off flashover. Thermocouples were placed at different locations a to d at the ceiling, d (this thermocouple was also fixed at the ceiling) to g at I. Books and magazines were ignited by the thermal radiative heat flux.

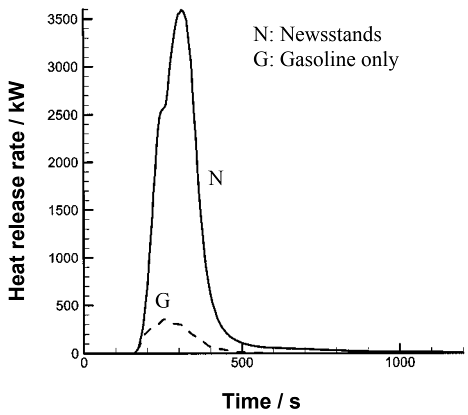
4. RESULTS

- Test 1

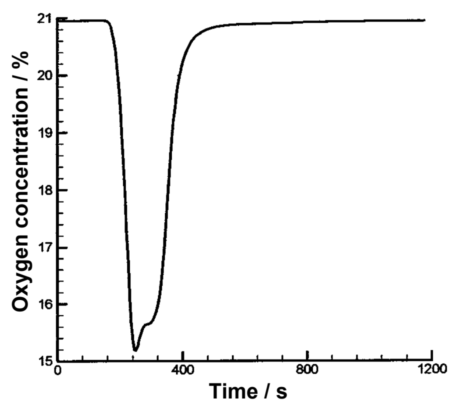
The heat release rate, oxygen consumption and air temperature curves are shown in Fig. 2. It is observed that the peak heat release rate can go up to 3.6 MW. The values were higher than 2 MW within a burning period of over 200 s. Air temperatures were up to 900°C as shown in Fig. 2c.

- Test 2

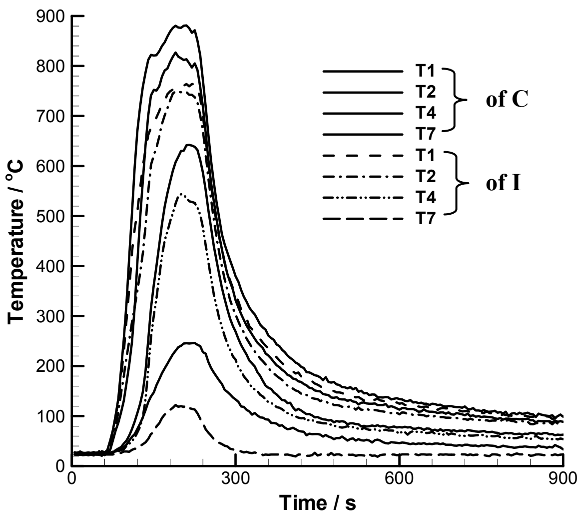
The heat release rate, oxygen consumption and air temperature curves are shown in Fig. 3. Note that the maximum heat release rate was up to 8 MW; and above 5 MW over 400 s of burning time. Consequences of such a big retail shop fire in a big atrium or public transport interchange should be watched carefully [2].



(a) Heat release rate

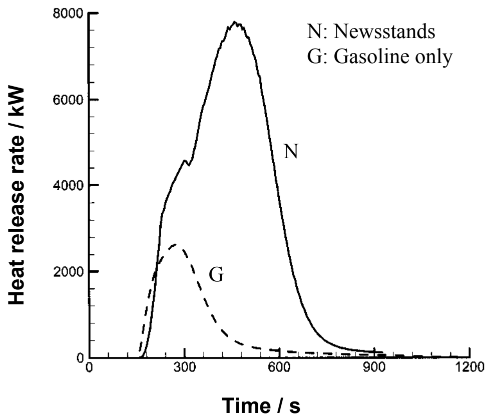


(b) Oxygen level

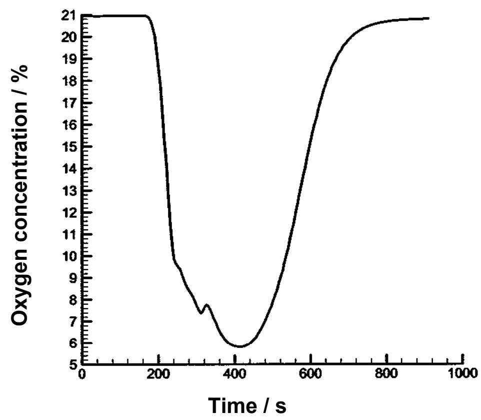


(c) Air temperature

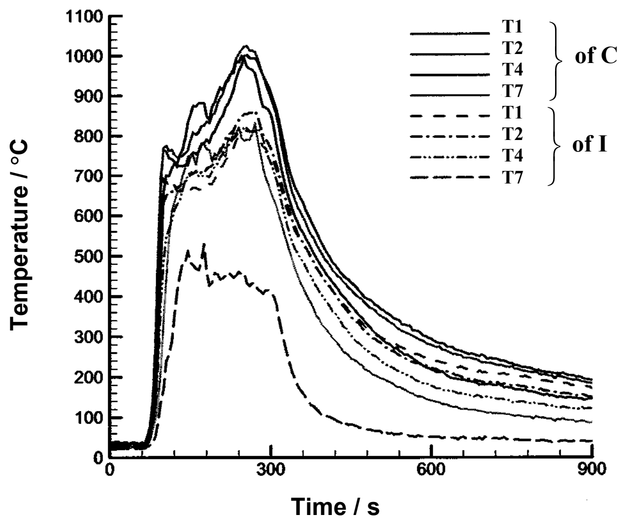
Fig. 2: Results for test 1



(a) Heat release rate



(b) Oxygen level



(c) Air temperature

Fig. 3: Results for test 2

- Test 3

Transient results on heat release rate, oxygen consumption and air temperature are shown in Fig. 4. All books, magazines and newspapers placed on the display boards were consumed completely. The peak heat release rate was only up to 3.2 MW. A possible explanation is that for the 15 kg of newspapers placed on the floor, only the surfaces were burnt to liberate lower heat release rate. Radiative heat flux at the floor level was measured for this set of test and presented in Fig. 4d. The maximum radiative heat flux was up to 28 kWm^{-2}, the value was above 20 kWm^{-2} within a long period of over 100 s.

5. DISCUSSIONS

The amount of gasoline used for setting off flashover was adjusted by reducing from a larger volume of 15000 ml. Sufficient gasoline was used but the liquid pool fire should not give out high heat release rates when other combustibles in the shop were ignited. Heat release rate curves for burning the gasoline only are shown in Figs. 2a, 3a and 4a. These curves demonstrated that heat liberated from the pool fire is much lower than from the shop contents.

The following are observed from the full-scale burning tests:

- Books and magazines stacked up horizontally on the floor were not so easy to burn completely by the downward heat flux. Only the surfaces might be ignited but not the whole stacks.

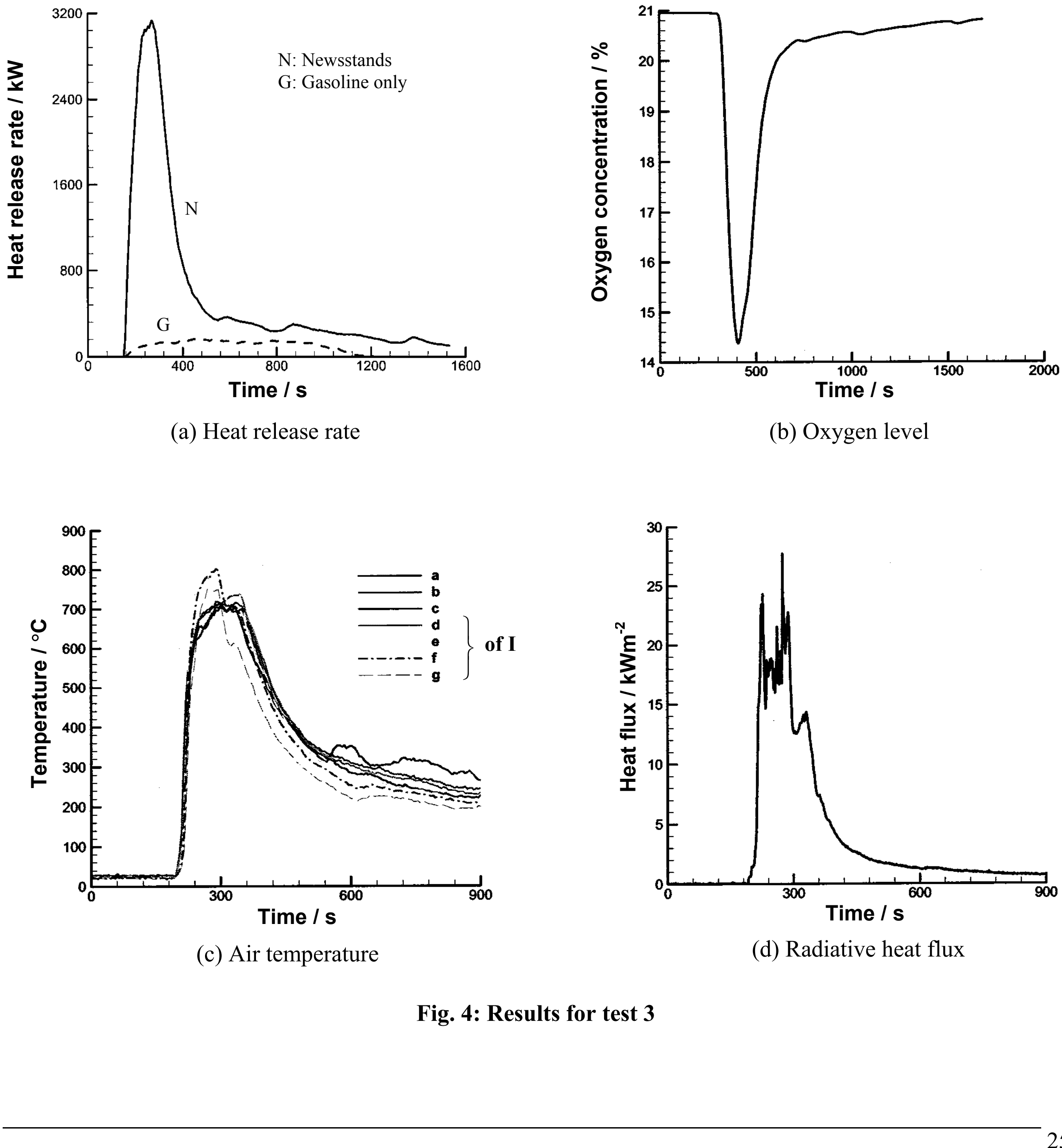
- Front pages of books and magazines placed horizontally on the display boards were turned over by the fire-induced air flow, and thus ignited easily. Without the air motion, the books and magazines would not be ignited so easily.
- Smoldering fires without flames were observed for some scenarios.

6. SUPPRESSION BY WATER MIST

Effect of water mist discharged [17] from a low-pressure fire suppression system at 12 bar operating pressure was also demonstrated. Arrangement was similar to test 3, but more gasoline of 8000 ml was used to sustain the flashover condition for a longer time.

Results on heat release rate, oxygen consumption, air temperature and radiative heat flux at floor level are shown in Fig. 5. For this test, the heat release rate increased rapidly, as more gasoline was used. Water mist was discharged manually at 105 s after ignition when the heat release rate reached 5 MW. The fire appeared to be extinguished within 99 s. No flames were observed and the heat release rate reduced to very low values.

After turning off the water supply, the fire ignited again 20 s later as shown by the heat release rate and oxygen consumption curves in Figs. 5a and b. All books and magazines on the display boards were consumed. For the newspapers placed on the floor, again, only the surfaces were burnt as in test 3.



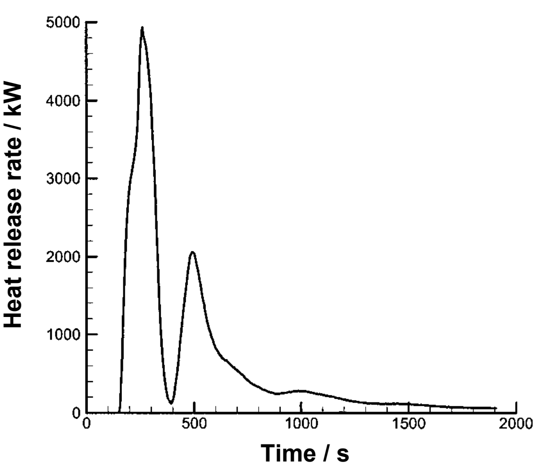
(a) Heat release rate

(b) Oxygen level

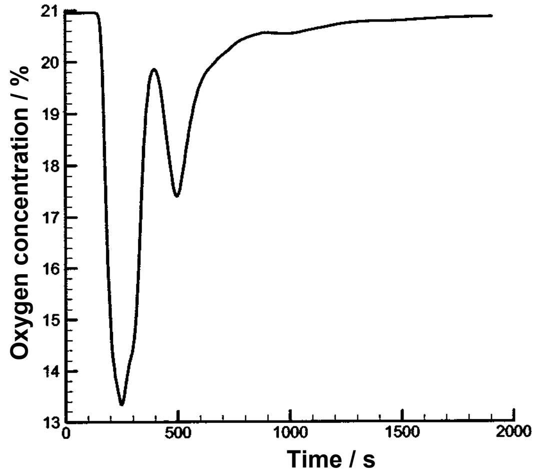
(c) Air temperature

(d) Radiative heat flux

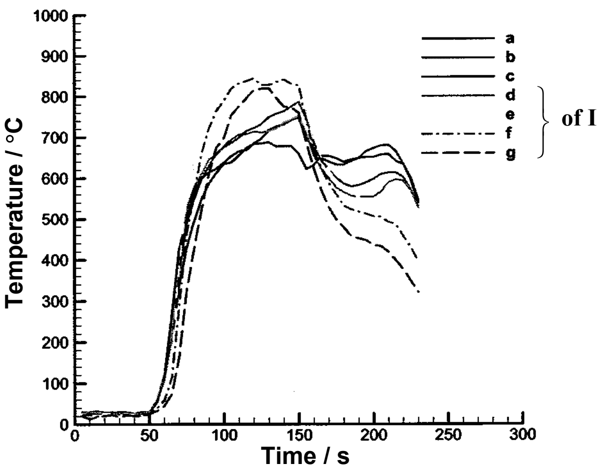
Fig. 4: Results for test 3



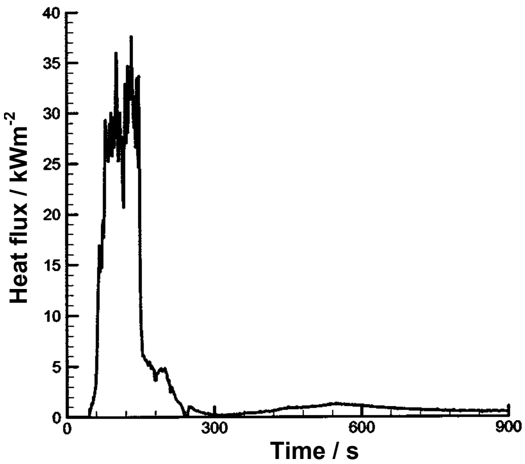
(a) Heat release rate



(b) Oxygen level



(c) Air temperature



(d) Radiative heat flux

Fig. 5: Results for test 3 with water mist discharged

7. CONCLUSION

The possible heat release rates of burning combustibles under flashover condition in a small retail shop were measured. Flashover was set off by a liquid pool fire with the amount of gasoline adjusted carefully. Once flashover occurred, say satisfying the criteria of 600°C near the ceiling or 20 kWm^{-2} of radiative heat flux recorded at floor level, the pool fire would only be sustained further for a short time afterward. Observations are:

- The peak heat release rate might be up to 8 MW as in test 2, with flame filling up the entire room. If the burning retail shop is in a large hall, this 8 MW burning object with the same size as the shop will give a big thermal plume [2].
- Water mist systems appeared to be useful in suppressing the fire. As demonstrated in this paper, the fire was extinguished within a reasonable time after discharge. However, the combustibles were ignited by themselves once the water supply was cut off. Water should be kept on discharging for some time. But doing this might give water damage.

Fire safety provisions are normally designed for protection against accidental fires. However, the number of arson fires over the world appears to be increasing [8,9]. The general public is now very concerned about the hidden fire hazard, even when they are traveling on an underground railway [9]. Perhaps, it is the right time to review the fire safety codes and the government is doing that at the moment. Obviously, a heat release rate database for local combustibles should be developed first [e.g. 5,6] and carrying out full-scale burning tests is necessary. Results are useful for designing smoke management system [18] in big halls such as shopping malls or public transport interchanges. Fire safety management [15] can be recommended based on such studies. For example, books and magazines are suggested not to be displayed vertically.

It is also proposed that performance of fire suppression systems such as those discharging water mist [17] to be demonstrated by similar burning tests. Anyway, further studies on burning those combustibles under flashover retail shop fires are necessary to give a better understanding on the possible heat release rates.

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