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SUPPORT ON CARRYING OUT FULL-SCALE BURNING TESTS FOR KARAOKES

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ABSTRACT

Consequent to a big arson fire in a karaoke establishment, a new Karaoke Establishments Bill is to be implemented for providing a safer indoor environment for karaoke activities. There, a long list of fire safety provisions is specified. There are concerns from the local industry as it has not been demonstrated that following the new requirements will ensure fire safety. Building refurbishment works on corridor width, dead-ends and fire resistant construction of the partition walls are the three main points. Earlier studies show that those points are not too critical in providing fire safety. Instead, the heat release rate of burning in a karaoke should be studied.

Heat release rate is an important parameter that will affect the course of a fire by providing the driving energy. Earlier surveys of local karaokes indicated that furniture, partition materials, surface linings, floor coverings and carpets are the key combustible items. The importance of studying the probable heat release rate by burning those combustibles in a karaoke box is pointed out.

Full-scale burning tests on selected designs of karaoke should be performed to identify key issues on fire safety. The heat release rate of burning in a karaoke box under local design can then be modeled with the aid of the measured data. Room fire models might be applied to understand the probable fire environment. Results will be applied to investigate how the fire safety provisions can be improved. These include providing better passive building design such as the application of fire retardants; and designing appropriate active fire protection systems. The information is necessary for implementing the new generation of building fire safety codes.

1. INTRODUCTION

Citizens in Hong Kong enjoy going to karaokes for entertainment, spending hours inside. Fire safety aspects in karaokes were not concerned until an arson fire killing 17 people happened. Karaokes are typically partitioned into many boxes, with long corridors, and are usually crowded with people during weekends and holidays. Fire safety provisions in karaokes are now watched carefully by the government.

"Karaoke Establishments" are now clearly defined by the Authority [1-3] to be any place used for karaokes. Licenses will be issued to those satisfying various requirements with fire safety as a main concern. A consultation paper was distributed for comments in 1998, with the proposed Karaoke Establishments Bill read for the first time in the Legislative Council on 7 February 2001. The karaoke business is a very big sector of the service industry in Hong Kong and safety must be provided to the public. Objective of the Bill is to establish a statutory licensing scheme for the regulatory control of karaoke establishments to improve their fire safety provisions. If a third reading is permitted, the bill will be implemented.

In that Bill, a very long list of fire safety requirements with due reference to those required by the Buildings Department or Fire Services Department is described. It is not clear whether including only all of the above would ensure fire safety [e.g. 4-8]. There is neither evidence that these requirements can really enhance safety in case of a fire, nor are the proposals supported by research and development work. The general response of the karaoke service industry is that fire safety should be enhanced so that the public would have more confidence to have entertainment in a safe karaoke. However, there is concern about the targets being over-set because no big accidental karaoke fires have occurred in the past. Most of the recommendations on fire protection systems are acceptable and in fact, have been implemented since the consultation paper was released. But there are reservations on three main points:

- Increasing the corridor width from 1.05 m to 1.2 m;
- Eliminating "dead-ends" of corridors; and
- Imposing fire resistance requirements on the partitions.

These three aspects were studied preliminarily [4-7]:

- For the first two points, results [e.g. 8] illustrated that changing the corridor width from 1.05 m to 1.2 m would not make much difference to both the fire environment as predicted from fire zone models [9] and the emergency evacuation pattern predicted [6,10,11].
- The presence of dead-ends, due to the relatively small size in each karaoke, again causes not much difference in the simulated total evacuation time, say within 80 s for typical karaokes.
- For the third point, there is too much emphasis on the post-flashover fire in the new code and so long fire resistance period is required. It happens in most fires that combustibles would not be burnt completely due to inadequate ventilation.

Therefore, setting up regulations on the above three without in-depth studies seems too rush. A fundamental question on providing fire safety has never been asked [12]:

How big is the fire?

To answer the above question, the heat release rates of a karaoke fire resulted from burning the combustibles items have to be understood. Heat release rate is an important parameter affecting the course of a fire by acting as the driving force. Reliable methods are not yet available to predict hydrolysis and the burning rate from basic materials properties, for most combustibles, and their configuration. There are some reports on estimating the heat release rates in burning a karaoke [e.g. 7]. However, no experimental data are available from systematic full-scale burning tests. The estimated heat release rates might deviate from those of an actual fire. Therefore, the heat release rate due to fire in a karaoke box for designing better fire safety provisions should be studied experimentally [13,14] to give key design information.

Issues and problems to be addressed are:

- Review on the combustion characteristics of combustibles identified in a karaoke box, i.e. furniture, audio-visual equipments, electrical appliances, partition walls and carpets.
- Carrying out full-scale tests on burning karaoke boxes with heat release rates measured by the oxygen consumption method.
- Modelling the resultant heat release rate in a karaoke fire due to burning combustible items with the aid of the experimental data.
- Modelling the probable fire environment in the karaoke establishment with room fire models.
- Studies on how fire retardants can be applied on providing better passive building design.
- Feasibility study on the active fire protection systems.

2. LITERATURE REVIEW

Very little research on karaoke fires has been reported in the literature. There has been work on the development of evacuation models such as studies of the exit requirements [10]; the effect of corridor width on evacuation [15]; and the use of virtual reality in evacuation modelling software [16]. Full-scale burning tests on karaoke without measuring the heat release rates and fire spreading over the surface and lining materials were also reported in Taiwan [17] where karaoke fires are quite frequent. To the best knowledge, their work consists of demonstrating how a karaoke fire occurs and develops by measuring the indoor fire environment. The heat release rate in burning the karaoke was not measured nor modeled from the items contained. Some work on fire spreading in corridor walls is in progress [18].

There are extensive measurements on the fire aspects of furniture [17,18], surface and lining materials [e.g. 19] with the oxygen calorimetry [20] at the Swedish Testing and Research Institute (SP), Sweden; Building and Fire Research Laboratory (BFRL), National Institute of Standards and Technology, USA; Fire Research Station (FRS), Building Research Institution, UK (in their Cardington full-scale burning facilities); and other big laboratories in USA, Japan, Australia and New Zealand. There are abundant works on the burning of single items [14,19-21], fire models, and work on burning some compartments such as libraries, retailing shops [22] and office workstations [23]. However, reports on studying compartments similar to karaoke fires are very few [e.g. 17]. Models estimating the heat release rates of burning assemblies from their contents based on those experimental results are still under development [e.g. 20].

Fire safety of karaoke was preliminarily studied by surveying the general aspects in local karaokes first. The associated codes were also reviewed [4]. With reference to the new regulations, a fire safety ranking system [5] was proposed to assess the fire safety provisions in a karaoke. From the result, three action levels of fire safety management are proposed. Both fire zone model [9] and evacuation software [11] were used to assess the three main points of concern in the karaoke. Combustibles in karaokes were identified to include partition materials, surface lining materials, furniture, and television sets. Data on heat release rate [7] measured by SP, NIST and FRS were analyzed. Equations appeared in the literature for calculating the heat release rates of these combustibles were assessed. Those results were used to estimate the heat release rate of fires occurring in karaoke boxes by the principle of superposition. The likelihood of a flashover [24] in a karaoke box was also investigated. Part of the results on the heat release rates was used as input parameters for simulating the possible fire environment using room fire models.

The above work is not validated through experiments [8] and so there are challenges on how reliable the results are. Therefore, the heat release rate in burning a karaoke box should be studied with full-scale burning tests.

3. COMBUSTIBLES IN KARAOKES

Field survey with support from the karaoke service industry [4,5] and frequent visits to karaokes for amusement indicated that combustibles in a karaoke box include:

- Furnishings including polyurethane sofa; coffee table with wood or other timber products; chair; and cushion.
- Finishes including partition walls with most of them made of timber chipboard, or plywood; surface lining materials; and floor coverings and carpets.
- Television sets and audio-visual equipment with wooden cupboard or other timber products.

It was found that furniture in some local karaokes would normally be assembled in the karaoke itself during decoration. Therefore, furniture in a certain karaoke (or even a chain of karaokes) would be very similar and usually made of common materials such as polyurethane foam, wood, cotton fibre, plywood and polyvinyl chloride.

Testing data on the above single items have been found in the literature:

- Furnishings

  Furnishings are those discrete objects usually with the total heat release rate measured [13]. Extensive studies on upholstered furniture have been carried out over the past 10 years [20]. One of the earliest systematic studies on furniture fires was perhaps due to Babrauskas and Walton [25]. 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 with the peak heat release rate modelled by two methods based on generic materials identification; and bench-scale measurement.

  One of the recent biggest projects is perhaps the project on Combustion Behaviour of Upholstered Furniture (CBUF) in Europe [19]. There, the heat release rate curve was estimated for use as input data to a fire model for predicting the probable fire environment. Basically, the heat release rate of upholstered furniture can be predicted by testing the composite samples in a cone calorimeter with three models: based on statistically-correlated factors; based on burning area-convolution technique; and a thermal fire spread model for mattresses. As reviewed later by Höglauder and Sundström [21], CBUF furniture can be further classified into 'domestic' and 'public' with the heat release rate modelled by a Gaussian function on time with parameters fitted by experimental studies.

- Finishes have dimension and fuel contents depend on geometry, usually the heat release rate per unit area was measured [13]. Examples are:

  - Surface lining materials

    In carrying out the ISO room-corridor [26] fire test, the heat release rate Q_{surf} depends on the heat input of the gas burner. In reality, Q_{surf} depends on whether there is an adjacent burning item and the heat input of that item. For small rooms such as a karaoke box [17], Q_{surf} was fitted by different functions including Gaussian function or t^2-fire for Classes I, II and III lining materials in Sweden [27].

  - Floor coverings

    Based on SP results, a t^2-fire can be fitted [21]. The heat release rate of carpets is described by an ultra-fast t^2-fire. For polyvinyl chloride- and wood-floor coverings, the heat release rate is described by a slow t^2-fire. But if there is another heat source of strength 300 to 500 kW placed next to it, an ultra-fast t^2-fire will be resulted.

4. STUDIES ON HEAT RELEASE RATE IN BURNING A KARAOKE BOX

Combustibles in a karaoke box have been surveyed to include furniture such as polyurethane sofa, cushion, coffee table and chairs; partitions and surface lining materials; floor coverings or carpets; and audio-visual equipment. Note that even paint surfaces might aid fire spreading [e.g. 28]. Furniture, particularly sofas, are likely to be ignited first. Several big fires started from the burning of polyurethane sofa in the past three years. Poor selection of partition materials, surface lining materials and floor coverings might give a much bigger fire, i.e. generating high heat release rate within a short time, and leading to flashover. Partitioning a karaoke into boxes might be good if the partitioning materials used have adequate fire protection such as treated with fire retardant.

Burning furniture of heat release rate Q_{furn}, surface lining materials of heat release rate Q_{surf} and carpets of heat release rate Q_{cap} have been considered before. The total heat release rate in the karaoke Q_K at time t [7] can be estimated by the principle of superposition [13]:

$$Q_K = Q_{furn} + Q_{surf} + Q_{cap} \qquad (1)$$

Taking domestic upholstered furniture in Europe reported in the CBUF project as an example, Q_{furn} (in kW) at time t (in minute) is:

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

For Class I lining in Swedish system, Q_{surf} (in kW) with a burner of strength between 100 kW and 300 kW placed next to it can be fitted by:

$$Q_{surf} = 300 \exp[-0.6 (t - 1.7)^2] \qquad (3)$$

Q_{surf} for burning Classes II and III linings might be a fast t^2-fire for an adjacent burner of strength 100 kW to 160 kW, i.e.:

$$Q_{surf} = 160 t^2 \qquad (4)$$

Burning carpets might give Q_{cap} to be an ultra-fast t^2-fire:

$$Q_{cap} = 640 t^2 \qquad (5)$$

Therefore, the total heat release rate Q_{K1} (in kW) for burning a karaoke box with lining materials classified as Class I under the Swedish system with carpet ignited at time t_{ic} is:

$$Q_{K1} = 2500 \exp[-0.4 (t - 3)^2] + 300 \exp[-0.6 (t - 1.9)^2] + 640 (t - t_{ic})^2 \qquad (6)$$

Bearing in mind that the surface lining would be ignited at 0.2 minute when Q_{furn} reached 100 kW.

For surface lining materials classified as Swedish Classes II or III, the total heat release rate in burning a karaoke box Q_{K2} (in kW) is:

$$Q_{K2} = 2500 \exp[-0.4 (t - 3)^2] + 160 (t - 0.2)^2 + 640 (t - t_{ic})^2 \qquad (7)$$

A pictorial presentation of the curves for the carpet to ignite in 5 minutes (i.e. t_{ic} = 5 minutes) is shown in Fig. 1. This illustrates the choice of lining materials is important after a furniture is ignited. For using Class I lining materials, the carpet might not be ignited as Q_{K1} dropped to 1000 kW at 5 minutes. This illustrates how important the choice of lining materials is.

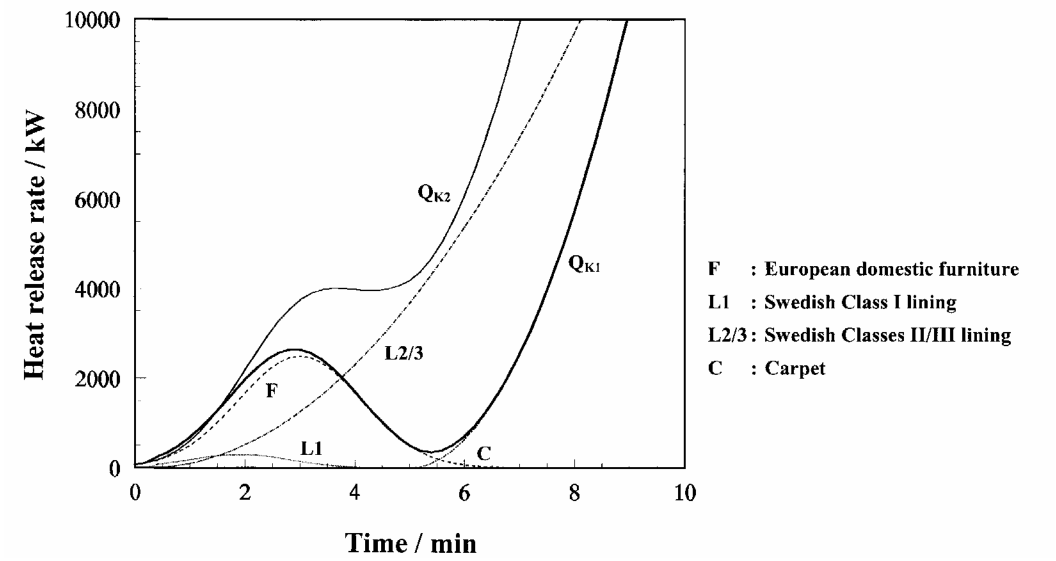


Fig. 1: Example of estimating heat release rate in a karaoke box

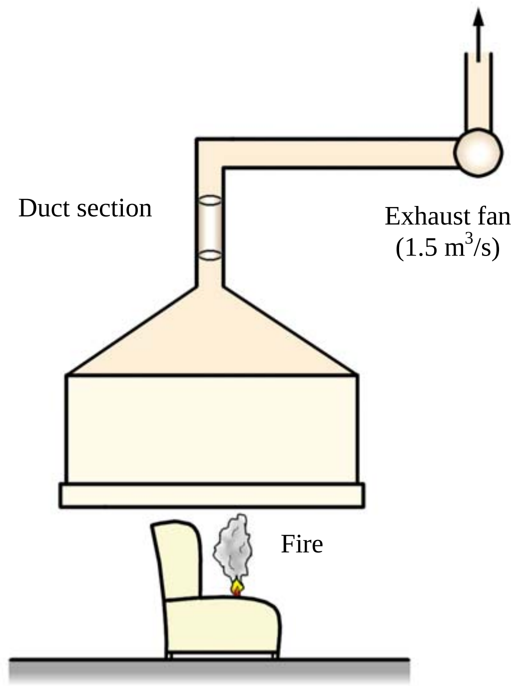
Estimation by equation (1) is only an approximation. Heat release from the first object would affect the burning behaviour of the second object. The phenomenon is complicated and empirical relations from full-scale burning tests need to be derived [13]. For example, whether the carpet would be ignited at 5 minutes is a question and can only be determined by full-scale burning tests.

Further, the radiative heat flux that might be encountered is an important element for studying a post-flashover fire. Heat release rate curves measured by a cone calorimeter would be different under different radiative heat fluxes. Therefore, modelling heat release rate of the karaoke box by the principle of superposition (1) is a very crude estimation.

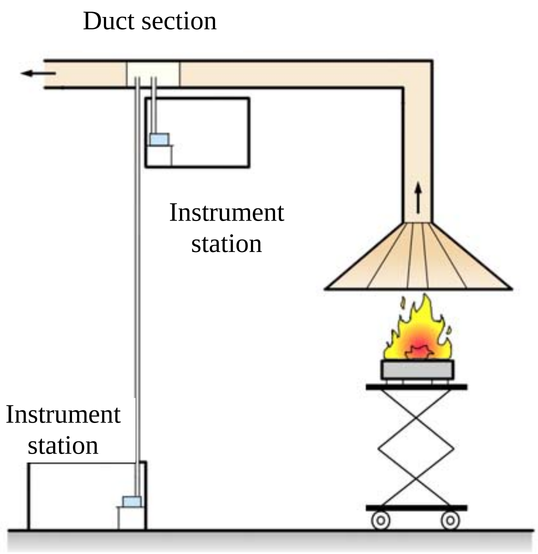
Facilities like the 'Exhaust Hood' at BFRL or the 'Industry Calorimeter' at SP should be developed to burn an actual karaoke box to measure the heat release rate as in studying an office workstation fire [23]. This cannot be carried out in Hong Kong due to many factors such as environmental concerns. With limited funding, an 'Assembly Calorimeter' has been designed and successfully built at Harbin, Hailongjiang, China for carrying out such studies.

5. OXYGEN CALORIMETRY AND THE POLYU/HEU ASSEMBLY CALORIMETER

The heat release rate when burning an object can be measured by the oxygen consumption method [14]. It has been shown in the literature that burning polymer with 1 kg of oxygen would give out 13.1 MJ of heat. This is a universal constant as most polymer materials have similar reactions on breaking the carbon-carbon, carbon-hydroxygen and carbon-oxygen bonds. The accurate and fast measurement of oxygen concentration, air temperature and air flow rate is of key importance. With the fast development of infra-red oxygen analyzers, it is now possible to measure oxygen concentration accurately and rapidly. The oxygen consumption method was applied to measure the heat release rate of small samples by cone calorimeter with adjustable heat flux due to a conical heater; the new single burning item (SBI) test [29]; and the heat release rate of burning furniture assessed by a furniture calorimeter. The concept was also applied in assessing the surface and lining materials in the ISO9705 room-corner fire test [26]; and burning assemblies by facilities such as the Industry Calorimeter at SP [e.g. 30] as shown in Fig. 2. Combustion products together with the air entrained are collected by a canopy hood connected to an exhaust system. The key instrument is a 'duct section' fixed at the exhaust duct with gas sampling tubes connected to an instrument station for measuring oxygen consumption rate as in Fig. 3.



Furniture Calorimeter



SP – Industry Calorimeter

Fig. 2: Equipment based on oxygen calorimetry

In Hong Kong, it is difficult to select a site for full-scale burning tests as land costs are far too expensive. More importantly, there are tight environmental protection regulations and real fire tests cannot be done. A site far from the urban area should be used for carrying out such studies. In this way, environmental impact of the burning tests can be minimized. Further, there should be water, electricity and heating supply in remote areas which are cold.

A facility, known as the PolyU/HEU Assembly Calorimeter, has now been developed in the small town of Lanxi in a remote area of Northern China, 200 km away from Harbin. There, a full-scale burning hall is designated. This is a joint project with the Harbin Engineering University (HEU) with some supports from the PolyU Area of Strategic Development (ASD) programme in Advanced Buildings Technology in a Dense Urban Environment (ABTDUE). The ‘duct section’ and the associated instrument including oxygen analyzer, carbon monoxide analyzer and carbon dioxide analyzer at the Research Centre for Fire Engineering of PolyU were moved successfully to that site in June 2001. A photo of the laboratory is shown in Fig. 4.

A chamber built as in Fig. 5 can be used for studying the heat release rate of karaoke assemblies. Trial tests by burning diesel give transient results on oxygen concentration and heat release rate as shown in Fig. 6.

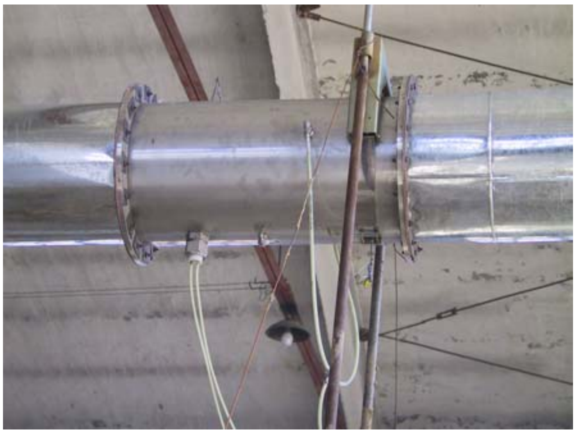


Fig. 3: Duct section and the instrument

Fig. 4: The PolyU/HEU full-scale burning hall

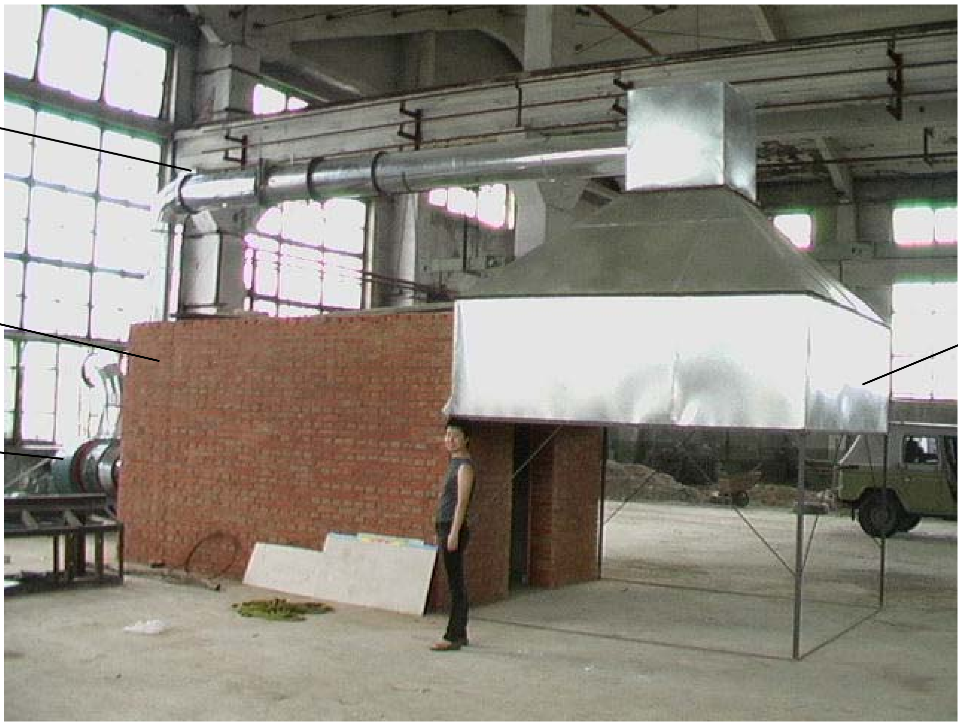
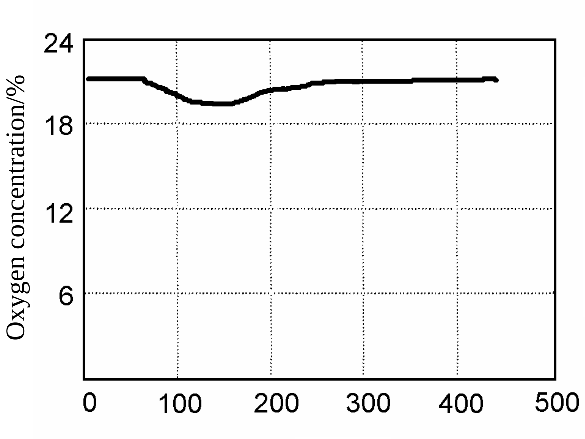
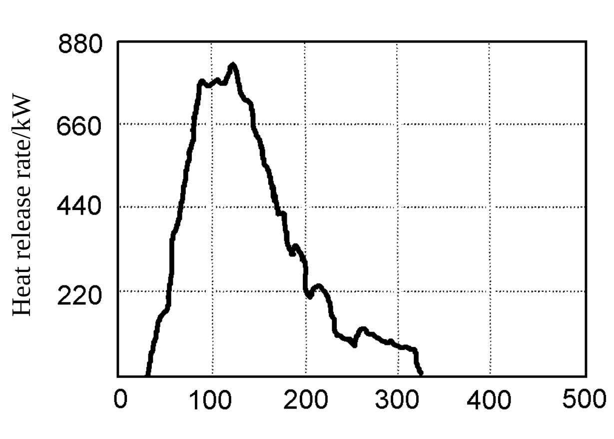


Fig. 5: Setup for karaoke box fire test at the PolyU/HEU site



(a) Oxygen concentration



(b) Heat release rate

Fig. 6: Typical results on burning diesel

6. EXPERIMENTAL STUDIES

Heat release rates of local combustible furnishings and finishes are not yet available. Partition walls used locally have been surveyed [31] and selected samples of typical furnishings and finishes commonly used locally will be tested. This will give characteristics curves for those combustibles. As pointed out by Lei et al. [17], the small size of a karaoke box might lead to a higher fire risk. A possible explanation is due to the likelihood of flashover as reported by Babrauskas and Walton [25] in their study of heat release rate for upholstered furniture fires. Results on the heat release rate can be applied to study the probable fire environment such as smoke layer temperature and interface height, the likelihood of flashover, flame spreading over the vertical wall, and fire spreading from the ignited object to adjacent objects through thermal radiation. Results might be applicable to predict the concentration of combustion products, particularly carbon monoxide and carbon dioxide if their yields are known.

Further, the local karaoke arrangement will be tested. Basically, typical karaoke boxes can be roughly divided into 3 groups as surveyed:

- Group A are normal boxes for up to 5 persons, with nominal size of about 2.5 m by 2 m and height 2.6 m.
- Group B are bigger boxes for 5 to 10 persons, with nominal size of about 3.5 m by 3 m and height 2.6 m.
- Group C are party rooms for more than 10 persons, with a bigger size of 5 m by 3.5 m, height 2.6 m.

Data on full-scale burning tests together with cone calorimeter results will be used on modelling the heat release rate of burning combustibles in a karaoke box. Both fire field modelling simulations with Computational Fluid dynamics [32] and zone models [e.g. 9] should be applied to understand a room fire with the heat release rate measured.

7. CONCLUSION

Heat release rate in burning a karaoke box is the most important parameter [e.g. 12]. This would give information for predicting [e.g. 20]:

- Fire environment such as smoke layer temperature, smoke layer interface height, radiative heat flux, rate of smoke flowing out and air intake rate through the openings.
- The likelihood of flashover.
- Upward flame spreading over walls.
- Ignition of items placed adjacent to a burning item.

If there are information on combustible product yields, their concentrations in the smoke layer can be predicted.

Fire safety regulations [e.g. 2,3] cannot be set up without support from research for local karaoke design. Local geometrical configuration and heat release database for combustibles [e.g. 14,19-23] must be clearly understood. However, this information is absent in Hong Kong. Therefore, rushing to set up fire safety regulations definitely would not be good to the community.

Heat release rate [e.g. 12,14] is the most important parameter in understanding a fire. Better understanding of it would be useful in recommending the use of furnishings and finishes combustibles for karaokes; and the fire safety provisions. In this way, a fire safe environment can be provided for those enjoying karaoke activities.

It is obvious that carrying out full-scale burning tests would be very expensive. Several millions of dollars had been spent already, though still far from expectations to give workable regulations. Further support from the SAR government and the service industry are welcome. Once again, it is difficult to determine the fire safety provisions without a good understanding of the heat release rate in burning karaoke boxes!

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