IMPORTANCE OF SMOKE TOXICITY IN FIRE HAZARD ASSESSMENT

C.L. Chow
Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

ABSTRACT

Smoke toxicity in a building fire should be watched carefully. In fact, people died in building fires were mainly due to smoke, not heat. Many tests were developed to determine the toxic potency data for different materials. Samples of surface lining materials commonly used in Hong Kong are tested to determine the toxic potency data of burning those selected materials. Smoke toxicity and the effects of toxic components of smoke on human beings following NFPA 269 and ASTM E 1678 will be followed. Such tests should be specified in the local fire codes.

Keywords: smoke toxicity, fire codes, materials behaviour

1. INTRODUCTION

In an accidental fire, harm is caused by falls, heat, suffocation or smoke inhalation. Effects brought by the toxicants inside the smoke should be watched carefully. However, the emission of smoke not just depends on what materials are burnt, but on how they are burnt. Different test methods were developed in the past three decades to determine the toxic potency of smoke that different materials released during combustion. The toxic potency data [e.g. 1] measured included:

- Effect concentration EC_{50} which is used for any observed response of the animals;
- The concentration LC_{50} of materials or fire effluent that produces death in 50% of the animals for a specified exposure time; and
- The concentration IC_{50} necessary to incapacitate 50% of the animals for a specified exposure time.

Further, the mean time-to-death LT_{50} and the time-to-incapacitation IT_{50} are also used with concentration fixed.

Studying smoke toxicity has become a worldwide hot topic recently. This had just started jointly in the Fire Research Institute in Sichuen and the Tsinghua University in this National 973 Fire Project [2]. Results obtained are very useful as reference for the legislation on selecting building materials. However, these were not studied locally nor appeared in the prescriptive fire codes [e.g. 3]. It is urgent to investigate how the smoke toxicity tests can be applied for assessing local materials.

A series of preliminary tests on the physical aspects were carried out in the NFPA 269 'Standard Test Method for Developing Toxic Potency Data for Use in Fire Hazard Modeling' [4] and ASTM E 1678 'Standard Test Method for Measuring Smoke Toxicity for Use in Fire Hazard Analysis' [5]. This test was selected as results can be applied for fire hazard assessment while implementing engineering performance-based fire code [6].

2. SMOKE TOXICANTS

Smoke toxicants can be divided into two types as reviewed before [7]:

- The first type is called asphyxiants or narcosis-producing toxicants, which can cause central nervous system depression, loss of consciousness or ultimately death. Effects depend upon the accumulated dose. Major asphyxiants include carbon monoxide (CO), hydrogen cyanide (HCN) and carbon dioxide (CO_2).

- The second type is irritants which would lead to sensory irritation and pulmonary irritation. Sensory irritation mainly refers to the irritations of eyes and the upper respiratory tract. Hydrogen chloride (HCl) is the most important halogen acid which is formed from thermal decomposition of polyvinyl chloride (PVC). HCl is both a potent sensory irritant and also a strong pulmonary irritant. Upon burning, fire retardants based on halogen such as chlorine or bromine would also give halogen acids including hydrogen bromide (HBr).

Values of 30-min LC_{50} for CO, HCN, HCl and HBr (denoted by $LC_{50}O_2$, $LC_{50}HCN$, $LC_{50}HCl$ and $LC_{50}HBr$) are 5700 ppm, 165 ppm 3800 ppm and 3800 ppm respectively.

3. FRACTIONAL EFFECTIVE EXPOSURE DOSE (FED)

In following ASTM E 1678/NFPA269 [4,5], transient concentrations of O_2, CO_2, CO, HCl, HCN and HBr of the smoke generated from a sample will be measured in a chamber to give a concentration-time curve. The concentration-time (in ppm/min) product was then obtained by integrating the area under a concentration-time curve. Fractional effective exposure dose (FED) can be calculated from:

$$FED = \sum_{i=1}^{n} \int_{t_0}^{t} \frac{c_i}{(ct)_i} dt \qquad (1)$$

where c_i is the concentration of toxic component and $(ct)_i$ is the concentration-time product of a specific exposure dose to produce the toxicological effect.

This can be written as:

$$FED = \frac{m[CO]}{[CO_2]-b} + \frac{21-[O_2]}{21-LC_{50}O_2} + \frac{[HCN]}{LC_{50}HCN} + \frac{[HCl]}{LC_{50}HCl} + \frac{[HBr]}{LC_{50}HBr} \qquad (2)$$

where m is -18 and b is 122000 for $[CO_2]$ less than 5%; and m is 23 and b is -38600 for $[CO_2]$ greater than 5%.

4. EXPERIMENTAL STUDIES

Tests on smoke toxicity can either be based on 'material' or 'chemical gases identified to cause troubles'. As the amount of those gases librated depends on the burning process, test based on those gases identified under some fire scenarios will be useful. Based on that, a concept known as the N-Gas Model was developed by the National Institute of Standards and Technology (NIST) on the toxic potency of smoke and is NFPA269/ASTM E 1678 [4,5]. A modified setup based on N-Gas Model was designed for local use.

Nine samples of surface lining materials commonly used in Hong Kong, i.e. pine, false ceiling, PMMA, beech, beech with protective coating, PVC, maple, teak and oak are selected. A sample of the testing specimen was placed at the combustion cell under the electric heater for 15 minutes. The specimen is either ignited by itself or by an igniter under the action of a 28.5 kWm^{-2} heat flux emitted by the electric heaters. The electric heaters were turned off after 15 minutes.

As HCl and HBr cannot be distinguished by gas sensor B in this study, concentrations of them were combined. But as values of the 30-min LC_{50} for both HCl and HBr are the same, i.e. 3800 ppm, the formula to calculate LC_{50} can be written as:

$$FED = \frac{m[CO]}{[CO_2]-b} + \frac{21-[O_2]}{21-5.4\%} + \frac{[HCN]}{150ppm} + \frac{[HCl/HBr]}{3800ppm} \qquad (3)$$

LC_{50} can be estimated by:

$$LC_{50} = \frac{\text{specimen mass loss}}{\text{FED} * \text{chamber volume}} \qquad (4)$$

5. RESULTS AND DISCUSSION

Values of LC_{50} of these nine common building materials were determined as:

Pine:	50.7 gm^{-3}
False ceiling:	84.4 gm^{-3}
PMMA:	255.5 gm^{-3}
Beech:	147.4 gm^{-3}
Beech with protective coating:	136.5 gm^{-3}
PVC:	30.8 gm^{-3}
Maple:	107.2 gm^{-3}
Teak:	98.8 gm^{-3}
Oak:	108.3 gm^{-3}

Results showed that the value of LC_{50} of PVC is the smallest, indicating that the largest amount of toxic gas was released from burning PVC when comparing with other test materials.

The value of LC_{50} of PMMA is the largest among the tested samples. Combustion products of burning PMMA were only carbon monoxide and carbon dioxide, without other toxic components. A possible explanation is due to the relative simple polymer structure of PMMA, containing only carbon, hydrogen and oxygen atoms $[CH_2C(CH_3)COOCH_3]_n$. Almost complete combustion might be resulted and the whole test specimen was burnt out.

Burning behaviors of different wood samples were quite similar and so the values of LC_{50} of them were roughly the same except pine. This might be due to the similar micro-structure of wood as having cellulose, hemi-cellulose and lignin. But in comparing the values of LC_{50} of beech and bench wood with protective coating, LC_{50} of beech with protective coating is lower and with higher concentrations of carbon dioxide and carbon monoxide emitted.

As PVC sheet has the lowest value of LC_{50}, it will be the most 'toxic' upon burning among the nine samples tested. Pine wood is the second one, false ceiling board the third, followed by teak, maple, oak, beech with protective coating, beech and then PMMA. The above is just a direct comparison on the measured LC_{50} values.

6. CONCLUSIONS

Smoke toxicity is an important issue. Nine samples of common surface lining materials including wood, PVC, PMMA and false ceiling were studied. LC_{50} was used as proposed to quantify the toxicity of smoke, due to chemical species CO, CO_2 and HCN on narcosis-producing toxicants, and HCl and HBr on irritants. Results on FED and LC_{50} are very useful in assessing materials while setting up design guides or regulations in selecting materials, and implementing engineering performance-based fire codes with a fire model [e.g. 8] with combustion products, consequences of different fire scenarios due to burning different combustibles can be assessed.

The standard test NFPA 269/ASTM E1678 [4,5] is a good candidate for assessing smoke toxicants. The tests are based on combustion products emitted under typical fire scenarios as compiled in the literature for most accidental building fires. The current paper is only a starting point highlighting the importance of the work.

In designing fire safety provisions, normally the fire load density is considered as the value specified in the local fire codes [e.g. 3]. This gives only the total heat released when all the combustibles are burnt out. No information on smoke toxicity is specified in the local fire codes yet. Results as in above should be specified as burning small samples of PVC as in the test will give out very toxic gases. This should be considered on implementing engineering performance-based fire codes [6].

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