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Comparison of toxic product yields of burning cables in bench and large-scale experiments

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Abstract

Toxic product yields from five commercial cables obtained from a steady state tube furnace (SSTF) method (IEC 60695-7-50, Purser furnace) are compared with results from a large-scale test, which uses the physical fire model in the proposed prEN50399-2-2 test, with the addition of effluent gas analysis, using Fourier transform infrared (FTIR), and for further comparison, a static tube furnace method (NF X 70-100). This work represents one of the first attempts to establish a relationship between bench- and large-scale toxic product yields for burning cables. This is difficult because the cables have been formulated for low flammability, and therefore do not burn consistently. The tube furnace burns the cable completely, whereas the large-scale test effluent is the result of a combination of flame spread and toxic product yields, both of which are fire scenario dependant. There is significant differentiation between cable types based on composition, and arising because only a portion of the cables burn in the large-scale test, accompanied by possible decomposition of hydrate sheaths. The fire stage of the large-scale test appears to have been replicated in an appropriate manner, given the correspondence of the CO_2/CO ratios. The yields of CO_2, CO, HCl and smoke show reasonable agreement, given the differences in the extent of burning, and the accuracy of the mass-loss data available for the large-scale test. The yields and extent of burning have been combined to demonstrate the estimation of toxic hazard for a particular fire scenario based around the large-scale test, which shows only marginal sensitivity to the differences in toxic product yield between the SSTF and the large-scale test.

Keywords: Fire toxicity; Cables; PVC; Ethylene-vinyl acetate copolymer; ATH; Polyolefin; Carbon monoxide

1. Introduction

The majority of deaths in fires result from inhalation of toxic gases [1]. The yield of toxic gases is dependent on both the fire conditions and the material formulation [2]. Electric cables frequently present a fire risk because of the remote location of their installation and the increasing quantities of installed cables. This risk translates into a significant hazard because cables are frequently installed in hidden channels that may breach the normal fire enclosures within a building, if not properly fire-stopped. Thus a cable fire could develop unnoticed, and then spread from compartment to compartment.

Fire (or smoke) toxicity has assumed a greater importance, particularly for high-risk applications. Estimation of the yields of toxic products within fire effluents is increasingly being recognised as a major factor in the assessment of fire hazard. Additionally, as prescriptive standards of fire behaviour for product acceptance are replaced by holistic performance-based fire codes allowing a wider range of materials to be selected, architects can now specify that new

Abbreviations: ATH, Aluminium hydroxide ($Al(OH)_3$); EHC, Effective heat of combustion; FPA, Fire propagation apparatus; FED, Fractional effective dose; FTIR, Fourier transform infrared; LC_{50}, Lethal concentration to 50% of population; PVC, Polyvinyl chloride; SSTF, Steady state tube furnace; SSTP Cat 7, Screened-screened twisted pair (a doubly screened data cable meeting the requirements of ISO/IEC 11801 class F)

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buildings require assessment by fire safety engineers in terms of flame spread and yield and distribution of toxic fire gases within the time required to escape [3].

1.1. Fire types

The yields of most toxic products are highly dependant on the fire conditions. As an enclosure fire develops, the temperature increases and oxygen concentration decreases. This has been set out as series of characteristic fire stages [4], from smouldering to post-flashover, providing guidance as to how to identify fire conditions from their CO_2/CO or equivalence ratio. This implies that if the same CO_2/CO ratio is obtained in two apparatuses, then the fire condition is also the same. However, as noted in the ISO standard, the presence of halogens will affect the CO_2/CO ratio; so, for polyvinyl chloride (PVC) cables it cannot be used directly to characterise a fire stage, because their values would be much lower, CO_2/CO ratios can still be used to compare the fire conditions of halogen-containing materials in different apparatuses. Table 1 shows the three most important fire stages, which have been investigated in this work.

This work describes the comparison of two bench-scale physical fire models with a well-ventilated large-scale fire scenario. However, it is important to note that although most large-scale fire tests are well ventilated, if a real fire is allowed to grow, transition through the different fire stages occurs, and for most materials the highest yields of the most toxic species, such as CO, are found under oxygen-depleted conditions. These are the conditions where the heat flux is sufficient to drive the decomposition and pyrolysis processes forward, but there is insufficient oxygen to allow the combustion reactions to go to completion. The factors controlling a material's fire gas toxicity are generally poorly understood, but have been shown to be somewhat independent of material [5] for many common aliphatic polymers composed of carbon, hydrogen and oxygen, but highly dependent on fire conditions. The range of different full-scale fire scenarios, and the difficulties in predicting large-scale behaviour on a small scale, has resulted in the determination of toxic product yields being neglected in the development of fire-retarded materials.

Attempts to determine the toxic product yields on a bench scale from burning materials and products rely on replication of the appropriate fire condition. The different approaches have been described [6]. Typically, the bench-scale apparatuses fall into three types, well-ventilated (only representing the least toxic fire stage), closed box (integrating all the fire stages into one result) and flow-through (allowing separation of fire stages through control of ventilation). The closed box tests such as the NBS Cup furnace (Pott's Pot), the Radiant Furnace test ASTM E1678 and tests using the NBS Smoke Chamber (ASTM E662 and ISO 5659-2) give a complete product yield of burning from well-ventilated right through to fully vitiated, but without giving any indication of how the yield varies with fire condition. Sampling from such devices during burning is possible but this may either deplete the fire gases if they are not returned to the box, or may change product, for example, by filtration prior to analysis, if they are to be recirculated. The French railway test (NF X 70-100) is a small-scale (~1 g) decomposition apparatus where the products are analysed and a toxicity index is generated, but there is no control over the ventilation for a particular decomposition rate. The other tube methods such as the fire propagation apparatus (FPA) (ASTM E2058) developed by FM Global, the DIN 53436 and the steady state tube furnace [7] (SSTF) (IEC 60695-7-50) all allow the possibility of controlling the fire conditions during burning. The FPA allows the rate of burning to vary under a constant heat flux, similar to the cone, but with much improved control of ventilation. In contrast, the DIN 53436 and the IEC 60695-7-50 force combustion by feeding the sample into a heated zone of increasing heat flux at a fixed rate, thus replicating steady state burning. As the sample moves into the furnace, lying in an 80 cm long silica boat, it experiences increasing radiant flux intensity until it ignites, then the flame spreads backwards slightly, to a cooler part of the furnace. At low oxygen concentrations, or for fire-retarded materials, where ignition is more difficult, the sample reaches a hotter part of the furnace before igniting, and again, the flame will stabilise itself, as it spreads a little way back up the tube. Thus flammable and highly fire-retarded materials are forced to burn at the same rate.

The aim of this work is to assess the degree of correspondence between the bench-scale SSTF data on toxic product yields from burning cables of low flammability with those from a well-ventilated large-scale test. The SSTF [7] is the IEC 60695-7-50:2002 (Purser furnace) which allows the rates of burning and ventilation to be

Table 1
ISO classification of fire stages, based on ISO 19706 [4]

Fire stage	Max temp. (°C)		Oxygen (%)		Equivalence ratio (ϕ)	$\frac{V_{CO_2}}{V_{CO}}$	Combustion efficiency (%)
	Fuel	Smoke	To fire	From fire			
1b: Oxidative pyrolysis	300–600		20	20			
2: Well ventilated flaming	350–650	50–500	~20	0–20	<1	>20	>95
3b: Underventilated flaming-post flashover	350–650	>600	<15	<5	>1	2.5–10	70–90