STUDY ON SMOKE TOXICITY

Danish Institute of Fire and Security Technology

Jernholmen 12, DK-2650 Hvidovre · Phone: +45 36 34 90 00 · E-mail: dbi@dbigroup.dk · www.dbigroup.dk

Toxic smoke is recognized as the major cause of deaths in fires. Nevertheless, regulation on smoke toxicity is often scarce or non-existent in the building industry, apart from a few exception countries where minor regulation exists. One of the key reasons for this is the fact that there is a strong lobby against regulating the toxicity in construction products due to the negative impact on the market of construction products these regulations might have. Moreover, Babrauskas [1] states that due to the poor correlation between small and large scale tests, it is inappropriate to regulate construction products on the basis of performance in bench-scale toxicity tests, while it is economically unsound to suggest requiring room-scale testing for assessing combustion toxicity.

The „Study to evaluate the need to regulate within the Framework of Regulation (EU) 305/2011 on the toxicity of smoke produced by construction products in fires“ is the most influential document that discusses the necessity of smoke toxicity regulation in EU. It shows that close to 80 % of assessed actors are against implementing any regulation related to smoke toxicity of construction products.

On the other hand, the transportation industry is strictly regulating smoke toxicity, as evacuation from different modes of transportation (e.g. planes, ships etc.) is impossible. Looking into how major actors (e.g. IMO, Boeing etc.) are working with toxicity testing and regulation could be a good background for further research on the topic. Moreover, this would allow for better practical understanding of toxicity and the implementation of its regulations and would be a good starting point in future in case regulation in the construction industry takes place.

Regarding the construction industry, this area may hold potential for toxicity testing. This could be in case regulations are introduced, or in case the smoke toxicity gains marketing significance (e.g. promoting “toxic-free” products).

1 In the early phase of a fire, the content of the room is the major contributor

It is important to separate the products of combustion produced by contents within a building such as floor coverings (rugs, mats, and carpets), curtains, upholstered furniture, televisions, white goods and other electrical equipment, and bedding from those produced by the construction products incorporated within the building.

In the early phase of a fire, which is decisive for safe escape, the content of the room is the major contributor for the fire development, smoke obscuration and smoke toxicity. The contribution of the building envelope to generation of heat and smoke starts only in a further developed phase of the fire and is less significant than the contribution from burning building contents. [24]

Another paper [25] presents results of an experimental campaign which had similar conclusions – the test results with regard to heat release rates, smoke and toxic gas emissions show that the main threat for occupants emanates from the room contents and not the construction products.

In [26] research literature comparing room-scale combustion toxicity performance of construction products is compared to bench-scale results. It is demonstrated that it is inappropriate to regulate construction products based on performance in bench-scale toxicity tests, while it is economically unsound to suggest requiring room-scale testing for assessing combustion toxicity hazards. Instead, it is demonstrated that the combustion toxicity hazards of construction products are best addressed by regulating their heat release rate characteristics.

In a report for the Dutch Government the authors concluded that based on real fires, when looking at the whole building and for the fires they investigated, there was no reason to conclude that today's applications of combustible insulation (mainly for roofs and external walls) lead to a specific risk to building occupants or a relevant contribution to the fire spread. However, it is stressed that for other applications, such as the use for internal dividing walls or in buildings with a high number of less self-sufficient people, the validity of this conclusion must be further investigated. The toxicity of smoke gases from combustible insulation materials is not significantly higher and in a limited number of cases probably lower than those of other building materials (for example wood). [1]

The Dutch Institute for Physical Safety investigated 34 fatal domestic fires of 2009 and concluded that in more than half of the cases, serious smoke development was mainly caused by the presence of foams in furniture and mattresses. The construction materials used for the buildings hardly had any impact on the fire development [27].

2 Effects of using extinguishing agents on toxicity

2.1 Firefighting agents

Fire extinguishing agents are combustible, and they thermally decompose at elevated temperatures. The flammability limits are higher with respect to ordinary fuels. However, the decomposition of fire extinguishing agents leads to the formation of toxic compounds such as HF and COF_2. [28]

The thermal decomposition products of four fire extinguishing agents, bromotrifluoro- methane (Halon 1301), pentafluoroethane (HFC 125), heptafluoropropane (HFC 227ea) and dodecafluoro-2-methylpentane-

3-one (C6F-ketone) have been reported [28]. The concentrations required for extinction were determined using a cup burner in an 8 litre volume, and the thermal breakdown was studied by introducing the agent into a propane flame in a tubular burner. It was found that both hydrogen fluoride and carbonyl fluoride (COF2), both of which are very toxic, were produced from each of the four firefighting agents. [2]

There is a significant potential for damage to aquatic ecosystems from firefighting foams. Unnecessary use of foams for prescribed burning operations should be avoided, however foams may be the most appropriate and least damaging tool for bushfire suppression where the ecological costs of traditional suppression methods are high. [29]

Based upon what is known about the nature of chemicals and of fire incidents where ecological impacts have been identified, it may be concluded that fire-water runoff can pose a threat to nearby aquatic environments. In cases of large industrial fires, it has been shown that nearby rivers, streams, and lakes bear the brunt of the ecological impact, and can sustain long-lasting damage. For most common house fires, this threat is comparatively minor. [30]

2.2 Water – use and limitations:

Water has properties which make it the most important extinguishing agent. No other extinguishing agent is available in such large quantities and at such a low price as water. It is easy to transport and to apply to the fire. Because it vaporises, water has good extinguishing properties.

Water is harmless in its normal state and does not produce any hazardous decomposition products. It is also harmless when used with most materials, at least in short term. However, substances that are toxic, corrosive, etc. can dissolve in water. Apart from water, spill water also contains three types of impurities. Residual products from the fuel may be formed at every stage in the breakdown process, from the original fuel to just soot. The substances washed out of the smoke belong to this category. The water may also contain varying amounts of substances present at the site prior to the fire. During the firefighting they are washed out and become part of the spill water. Finally,, substances may have been added during the operation, such as foaming agents. [31]

2.3 Foam – use and limitations:

Foam is one of the more common extinguishing agents used when tackling a variety of fires, mainly fires involving liquids and in buildings where interior firefighting is considered to be inappropriate.

When ordering foam from concentrate, its environmental impact should be included as part of the decision-making process. One of the problems with foam concentrates is that they do not comprise a single substance. They contain a mixture of substances, and the manufacturer is the only one aware of their content. Consequently, the manufacturer has a great of responsibility in terms of stating the product’s impact on the environment. [31]

2.4 Powder - use and limitations:

Powder is the extinguishing agent primarily recommended for portable fire extinguishers. This is mainly due to a high extinguishing capacity in relation to weight and price.

The fine-grained powder is effective in extinguishing fires, but it also produces a fine dust, which limits the suitability for using powder extinguishers.

As powder is in solid form, this type of extinguishing agent is not particularly active in the environment. As a result, using powder helps prevent the contamination of water and air with impurities. This differentiates it from the liquid-based extinguishing agents, such as water and foam. [31]

2.5 Gaseous extinguishing agents – use and limitations:

Common substances such as nitrogen, carbon dioxide and argon, as well as a number of halogenated hydrocarbons and mixtures of these are representatives of gaseous extinguishing agents. Gaseous extinguishing agents are rarely the most effective choice from a technical standpoint, in terms of extinguishing a fire. In fact, the major benefit of this extinguishing agent is that it is clean. Most gases cause no or only slight damage if the extinguishing system is set off accidentally. Gaseous extinguishing agents may be a good choice if something of great value is being protected or the downtime must be kept to a minimum.

The problems with gaseous extinguishing agents mainly concern the fact that they are toxic or at least displace the oxygen in the air. Also, some of them have a negative impact on the environment and they cannot be disposed of after a firefighting operation.

Gaseous extinguishing agents have two different types of toxic effect. On the one hand, they displace the oxygen in the air and on the other, these gases can cause poisoning, with different effects on the body's functions. [31]

3 Effect of fire retardants on the smoke products

Most of the study of flame-retardant chemicals has been done on the chemical in its original form. Exposures to the general population are likely to be to the original form of a flame retardant chemical due to leaching from products. However, firefighters are exposed to the combustion products of flame retardant chemicals as well as the original forms of the chemicals. Of great concern is that **dioxin** and **furan** compounds can be produced during the heating and combustion of halogenated flame retardant chemicals. Dioxin and furans are toxic chemicals that can lead to liver problems and elevated blood lipid levels and are considered to be reproductive toxins as well as carcinogens. While the combustion of halogenated flame retardant chemicals is certainly not the only source of dioxins and furans, an increased exposure to these harmful chemicals could result from the presence of flame retardant chemicals in a fire. [32]

Most fires produce polycyclic aromatic hydrocarbons (**PAHs**), a class of chemicals that includes carcinogens and reproductive toxicants. However, the fires with flame retardants produced tenfold greater amounts of PAHs, and more of the more toxic PAHs, than fires without these flame retardants. So the combustion of products that contain halogenated flame retardant chemicals is likely increasing the exposure potential not only of these flame retardant chemicals, but of two other classes of chemicals (dioxins/furans and PAHs) with reproductive toxicity and carcinogenic properties as well. [32]

Another area of concern associated with the combustion of chemically flame-retarded materials is the production of **carbon monoxide, smoke, and soot**. Carbon monoxide and smoke are considered major contributors to death from a fire and high levels of soot will decrease visibility in a fire. An increased production of all three elements, carbon monoxide, smoke and soot, is observed during combustion of polyurethane foams that had been treated with flame retardant chemicals (such as decaBDE and TDCPP) compared to foam that had not been treated. Polyurethane foam is commonly used as the padding material in upholstered furniture, mattress pads, and other consumer products. An increased production of these three elements in a fire could contribute to an increased potential of harm or even death from a fire. [32]

In [33], a detailed explanation on toxicity of each of the flame retardant types can be found, namely Halogen-containing flame retardants, Phosphorus-halogen containing flame retardants, Phosphorus-containing flame retardants, Nitrogen-containing flame retardants, Mineral flame retardants and Nanoparticles used as flame retardants.

When talking about toxicity problems when using flame retardants, a few issues need to be addressed [34]:

- The overall toxic effects of smoke on fire victims and the immediate effects of flame retardants on the toxicity of the smoke generated by a material containing such additives (i.e., the smoke toxicity of flame retardants and of the associated smoke);
- The individual potential acute and chronic toxicity of flame retardants on their own, such as during manufacture, during disposal or as a result of their migration into the environment (i.e., the inherent short-term and long-term health effects of the flame retardants);
- The effects of flame retardants on the environment, such as any potential activity as carcinogens, mutagens or as toxicants affecting wildlife (i.e., the potential environmental effects of the flame retardants);
- A life cycle analysis for the generation of toxic combustion products and of environmental damage when comparing flame-retarded products with non-FR products

The use of flame-retardants presents an important benefit to society and the environment via the improvement of fire safety. Undoubtedly not all flame retardants ever developed or about to be developed are safe from all points of view, but the use of appropriate scientific knowledge and the regulatory environment can effectively ensure that if any specific material is shown to be unsafe it is kept away from consumers. In summary, this survey shows that the appropriate use of flame-retardants, as a class, effectively provides improved fire safety via lowering the probability of ignition, the heat released and the amounts of smoke, combustion products and dangerous environmental toxicants. In consequence, the use of flame-retardants increases the available time for escape from a fire. [35]

4 Conclusions

The area of regulation in particular is widely discussed in wakes of large fire accidents and the EU study on the necessity to regulate construction products. Considering the list of trends surrounding smoke toxicity bellow, it appears that there is not enough consensus on the topic to introduce a related regulation in construction. In addition to the lack of consensus there is also a majority lobby opposing such regulation. However, it should be mentioned that aftermath of large fire accidents calling for regulation of smoke toxicity could tilt the positions considerably [36]. In transportation, there are established (or semi-established) regulations and standards related to smoke toxicity.

The area of environmental concerns related to smoke toxicity is currently not yet developed. Respondents in this area are concerned by smoke production, especially emitted from large forest fires (e.g. recent Australian fires) rather than by the smoke toxicity emitted by products.

Lastly, the market dimension of the smoke toxicity topic would likely be heavily affected by introduction of regulation. It could drive out some existing construction products. The marketing potential of “toxic smoke free” construction products has not been directly supported by any respondents. However, since some construction products already emit very little amount of toxic smoke, some manufacturers could fairly easily adopt the “toxic smoke free” label if the need arises.

In summary, the area of smoke toxicity currently is on the public agenda mostly in regard to its regulation. While some of the producers and the sustainability certification systems are aware of the topic and hold opinions on it, the demand for quantification of smoke toxicity will likely not come from them. The regulation could take different forms, from product specific to holistic. The product specific regulation is, based on the pre-study (EU) 305/2011, not supported by the respondents and its introduction will therefore depend on EU agenda. On the other hand, the holistic regulation of smoke toxicity is seen as unfeasible [24], [26] as it would have to cover all room fittings. Therefore, it would be reasonable to assume, that a more specific and simple regulation would precede a holistic one.

Below are listed the summarized conclusions of the study of trends surrounding smoke toxicity:

Regulation

1. There is no holistic regulation on the toxicity of smoke produced by construction products in any EU country.
2. Of the non-EU countries, Japan and China have regulation directly related to the toxicity of smoke produced by construction products. However, these regulations are only for specific products and/or specific situations.
3. In transportation the regulations are much more commonplace. Each mean of transport (trains, planes, ships) has its own specific regulation.
4. It seems like the support in favour of introducing regulation is comparatively scarce. The majority of the project steering committee and of the registered lobbyist are against the introduction of regulation on the toxicity of smoke produced by construction products.

Sustainability certification systems

5. None of the assessed sustainability certification systems cover smoke toxicity in any products.
6. None of the assessed sustainability certification systems see smoke toxicity as crucial in relation to construction products.

7. Most environmental toxicity concerns of the assessed sustainability certification systems are not related to smoke toxicity.

Producers

8. Quantification of smoke toxicity in construction products will likely introduce of barriers of trade for certain products and drive innovation of non-toxic construction materials.
9. "Toxic smoke free" construction products are currently not seen as having a large market potential due to the doubts over the significance of the toxic smoke produced by construction products. This would change if a related regulation is introduced.

A significant problem in understanding and evaluating toxic hazards in fires is to identify the range of toxic species evolved from different materials under different combustion conditions in fires, and to determine their toxic effects individually, and in combination in mixed fire effluents. In particular, are the main toxic effects of fire effluents caused by exposure to a small number of key toxic gases or are a larger number of more exotic chemical species important? [2]

It has been known for many years that one toxic gas, carbon monoxide, is evolved at high concentrations in most fires. Rescued fire survivors often show signs of carbon monoxide intoxication, with high concentrations of carboxy-haemoglobin (%COHb) in their blood, and fire fatalities dying as a result of exposure to toxic smoke usually also have fatal or near fatal %COHb levels. Carbon monoxide is undoubtedly of major importance as a cause of incapacitation and death in fire victims, but is it the only toxic product that needs to be considered? Measurements of the chemical composition of combustion products, including very detailed studies of tobacco smoke and effluents from a variety of polymeric materials, have shown them to contain hundreds of different chemical products, many of which show significant toxicity.[1]

There are a large number of different methods used for bench-scale assessment of combustion toxicity, and lack of consensus surrounds the applicability of test data to fire hazard assessment. Toxic hazard data should not be used in isolation but should either be a part of a classification scheme and/or as a part of the input to fire risk and fire safety engineering assessments. It is important that uncertainty or confidence limits should be used with toxic hazard data, because they are often relatively large. Fire effluent toxicity does not have a unique value but is a function of the material and the fire conditions, particularly temperature and oxygen availability in the fire zone, and also the fire environment (enclosure, geometry and ventilation). In order to assess the fire hazard, toxic hazard data must be relevant to the end use fire situation, which can be defined using the ISO classification of fire stages. [1]

Globalisation of trade and relaxation of national barriers drive the need for international harmonisation of toxicity testing. ISO specifications and standards provide a common basis on which to determine toxic hazard. A number of standard fire smoke toxicity tests are available and it is important to consider their relevance and limitations before selecting a method. Some of these tests do not appear to represent any fire stage; some represent several fire stages separately; others represent the progress of a fire through an indeterminate number of stages. Further, some test methods produce data, which are a function of both the flammability of the specimen and the yield of toxic products, while others provide toxic product yield data, which are independent of the burning behaviour. [1]

The general trend has shifted from standard tests, which include precise details of apparatus, procedure, method of assessment and specification of results, to, more recently, approaches which define the apparatus and procedure necessary to obtain data relevant to end-use fire situations. The latter requires the involvement of suitably qualified personnel to define the necessary test conditions, effluent analyses, and to interpret results to ensure they are relevant to the end use application. [1]

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