

Introduction

The purpose of this document is to clearly quantify the fire performance of expanded polystyrene (EPS) when used as an insulation material in buildings. This document will consider all aspects of the fire performance of EPS in terms of heat release, flame spread, smoke production and toxicity and its contribution to the propagation of fire. Detailed information is provided on the characteristics of EPS foam as a basis for evaluating its behaviour when subjected to ignition sources. The performance of fire retardant additives is also evaluated. This information can be used for hazard assessment taking into account the complexity of a real fire and the difficulty of modelling real fire situations from scaled tests.

General

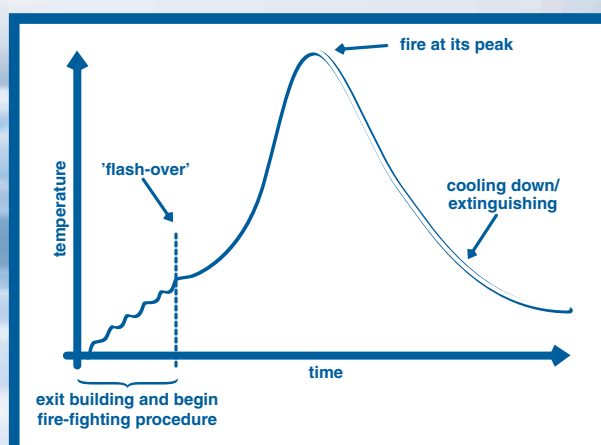
Expanded polystyrene is derived mainly from styrene monomer and expanded to form a cellular structure substantially of closed cells. When considering the fire behaviour of any building material it is important to realise that the assessment must be based on its performance in end-use conditions. This performance will depend on not only the chemical nature of the material but to a greater extent on its physical state. Thus the important factors which must be considered in determining the potential fire hazard of EPS are:

- the foam density and shape of the product
- its configuration relative to an ignition source
- the use of any bonding to a substrate or facing
- the location of the product (which will influence the heat transport)
- the availability of oxygen (ventilation)

Stages of a Building fire

(How a Building fire develops)

When a building is in everyday use at normal temperature conditions, there is a natural balance between flammable materials and oxygen in the environment. However at the initial stage of a fire, ignition energy comes into contact with the flammable material. Above a temperature of approximately 200° C, the material will give off flammable gases, which will combust either due to the original ignition energy or spontaneously. In the case of gases, combustion can lead directly to flames whereas with solid materials, such as furniture, they first become glowing ignition sources. In the first stage of a fire, there is a gradual build up of heat energy in the form of combustible gases. Up to this point the temperature is still relatively low and the fire is still localised within the building. Then all of a sudden a development takes place, called 'flash-over', in which the temperature increases significantly and the fire suddenly spreads all over the compartment. After this flash-over the chances of rescuing people and equipment are greatly reduced. The fire then spreads throughout the whole of the building and will finally go out without human intervention due to the lack of flammable materials.



The behaviour of EPS in a fire

General

Like practically all organic building materials polystyrene foam is combustible. However in practice its burning behaviour depends on the conditions under which it is used, as well as the inherent properties of the material. These inherent properties differ depending on whether the cellular material is made from EPS with or without a fire retardant additive. The bonding of other materials to cellular polystyrene also considerably affects its burning behaviour. For example, foil-faced products have an improved surface spread of flame performance. When installed correctly, expanded polystyrene products do not present an undue fire hazard. It is strongly recommended that expanded polystyrene should always be protected by a facing material, or by complete encapsulation.

When burning, expanded polystyrene behaves like other hydrocarbons such as wood, paper etc. The products of combustion are basically carbon monoxide and styrene: during a fire, the styrene may be further decomposed, giving off oxides of carbon, water and a certain amount of soot (smoke).

EPS is produced in two types: the standard quality and the fire-retardant modified quality, designated by the code 'SE'. Flame retarded or SE grades, which make the expanded material much more difficult to ignite, considerably reduce rates of spread of flame.

Some countries, such as those in Scandinavia, only use the standard grade, whereas others, Germany for example, only use the SE grade. However, in many European countries, both grades are used.

If EPS is exposed to temperatures above 100° C, it begins to soften, to contract and finally to melt. At higher temperatures, gaseous combustible products are formed by decomposition of the melt. Whether or not these can be ignited by a flame or spark depends largely on the temperature, duration of exposure to

heat and air flow around the material (the oxygen availability)¹. Molten EPS will normally not be ignited by welding sparks or glowing cigarettes; however, small flames will ignite EPS readily unless it contains flame retardant additives (SE Grade). The transfer ignition temperature is 360° C. In the case of EPS-SE, this is 370° C. These values indicate that if melted EPS disintegrates then combustible gases are only formed above 350° C. In the absence of an energy source (pilot flame) the self-ignition temperature of melted EPS in its standard grade is 450° C. After ignition of standard grade EPS, burning will readily spread over the exposed surface of the EPS, and it will continue to burn until all EPS is consumed. While the low density of the foam contributes to the ease of burning through a higher ratio of air (98%) to polystyrene (2%), the mass of the material present is low and hence the amount of heat released is also low.

Contribution to the propagation of fire

Building Regulations all over Europe stipulate requirements in respect of a complete structure and work on the basis of specifying the contribution to the propagation of fire, from the response to fire-load density on the surface of a structural component. This is called the 'Reaction-to-Fire' classification system.

Classification systems and fire tests differ all over Europe; however, a system of "Euroclasses" is developed these days and is expected to be available in 2000.

Fire-retardants

The presence of fire retardant additives in SE grades leads to significant improvements in the fire behaviour of EPS. While the complexity of a real fire situation makes it very difficult to predict overall fire performance from laboratory tests, there are several small-scale tests which clearly show that it is much more difficult to ignite EPS made from grades with a fire retardant additive than standard grades.

In the presence of large ignition sources or significant heat fluxes, e.g. greater than 50 kW/m², from fires involving other material, EPS SE grades will eventually burn, reflecting the organic nature of polystyrene. In such instances the building is usually beyond the point of rescue³.

EPS-SE grade contains a small quantity of a fire-retardant agent (max. 0.5 %). This is the fire retardant hexabromocyclododecan (HBCD). This has a beneficial effect when EPS is exposed to a fire source. The foam shrinks rapidly away from the heat source, thus reducing the likelihood of ignition. The decomposition products of the additive(s) cause flame quenching, so that when the ignition source is removed, the EPS will not continue to burn.

HBCD is a so-called cyclo-aliphatic organobromine compound and is not comparable with the aromatic fire retardants (PBBs and PBBOs), the use of which has been banned for some time. Indeed, HBCD does not form any toxic dioxins and furanes during combustion. This was concluded by the German Ministry for the Environment in 1990, for the combustion of polystyrene with an HBCD content that was at least five times greater than normal (3 percent by weight). They found that HBCD is not a source for the build-up of polybromodibenzofuranes and -dioxins when using different types of combustion oven over a temperature range of 400 to 800° C². The same result had previously been concluded by the Dutch Ministry for the Environment³ in 1989 for pyrolysis of polystyrene with an HBCD content of 10 percent (in fire retardant modified EPS there is only 0.5 %). A study in 1992 by the well known German Fresenius Institute⁴ itself showed that in the HBCD itself there were no brominated dioxins or furanes to be demonstrated. Recent research at the Karlsruher test incinerator 'Tamara' has demonstrated that the combustion of polystyrenes in a modern combustion oven is an environmentally friendly method of recycling in terms of emissions.

Also as HBCD is insoluble in water there is therefore no risk due to migration to water⁵.

Heat Release

The rate of heat release has lately been considered an important parameter for assessing the fire behaviour of materials. The test method developed as ISO 5660 using a cone calorimeter allows specimens to be burnt under a range of impressed heat fluxes. Tests in an industry-laboratory showed that EPS board shrank rapidly away from the heat source and collapsed into a film of molten polystyrene. No flaming ignition was observed at a heat flux of up to 20 kW/m². For higher heat fluxes, the overall rate of heat release (RHR) and peak RHR were lower for SE grades with a fire retardant additive than for standard grades.

The calorific value of expanded polystyrene materials (40 MJ/kg) is about twice that of timber (18.6 MJ/kg) but taking into account the comparative densities of the two products, the calorific volume by volume of expanded polystyrene materials is 540 MJ /m³ to 1250 MJ /m³ compared with 7150 MJ /m³ to 10 400 MJ /m³ for cellulosic products, such as fibre, insulating board, or timber.

The overall heat content of materials influences fire severity in terms of fire growth and the rate of release of heat content is of major importance. This is very dependent on combustion conditions. Heat release from expanded polystyrene materials is about three times as rapid as from softwood timber, but is of much shorter duration^(6,7,8).

The extent and rate of heat release is limited primarily by ventilation. For example, a foam of density 16 kg / m³ requires over 150 times the volume of air to achieve complete combustion. Complete combustion of expanded polystyrene is unlikely to occur, so its full potential heat is rarely released

A 200mm-thick layer of EPS with a density of 20kg/m³ represents the same amount of energy as a 17mm-thick layer of pine wood. But who hesitates to use 17mm-thick pine as unprotected surface on a ceiling or a wall?

Smoke

Smoke is an important factor in fire. A high density of smoke will inhibit the search for an emergency exit thereby increasing the risks to occupants. Smoke fumes can also be toxic or have a low oxygen content, while (hot) soot particles are able to block and adversely affect the breathing organs.

When assessing potential smoke emission from expanded polystyrene materials in a building under fire conditions, essential factors to be considered include the possible extent of flame spread over any surface designed to protect expanded polystyrene materials, the ventilation conditions and the rate of decomposition of the polystyrene. Effective surface protection will restrict flaming to areas where the coating has failed and where molten polystyrene or gaseous decomposition products have escaped through joints and small fissures.

Prediction of the precise smoke-producing potential of polystyrene is difficult because of the wide range of combustion conditions likely to be met within the actual fire. Generalised conclusions from small scale tests have been substantiated by evidence from fire incidents. In a flaming fire expanded polystyrene materials produce more smoke from a given mass of material than most other materials. It should however be noted that expanded polystyrene materials contain only 2 % by vol. of solids.

In actual fires where much smoke is produced, it is often anticipated that this originates from burning EPS roof insulation. In extreme cases this claim is made even for fires in buildings without any EPS insulation. In fact, most of the smoke originates from materials such as burning wood, asphalt felt and furniture, especially after the first short phase of fire.

Flame Spread

Flame spread is a process of progressive ignition along a continuous surface. The extent and rate of flame spread depend largely on the ignitability of, and rate of heat release from, a combustible material. In linings where expanded polystyrene material is attached to a rigid substrate and is provided with a protective exterior facing, the risk of flame spread is also affected by the physical / thermal properties of the surface on to which the expanded polystyrene material may have melted.

The proximity of the substrate and the degree of integrity of the protective facing (where it still remains) as well as the design of fixings and joints govern the distribution of any molten polystyrene and the supply of air and heat to the combustion zone. If adhesive has been used overall to attach expanded polystyrene material to a surface facing, melting will result in attachment to this surface but where thick sheets have been installed, particularly horizontally, failure of the surface facing can result in the formation and falling of molten drops, often flaming.

Where localised failure of a protective facing has occurred, air supply to, and the orientation of, the surface of the exposed expanded polystyrene material are important in determining the subsequent risk of flame spread, (e.g. in a cavity wall insulated with expanded polystyrene material), extensive spread is unlikely because of lack of circulation of combustion air^(9, 10).

From recent research it is possible to quantify the contribution made, separately by the insulant, to fire growth in free ventilated enclosures where expanded polystyrene material insulant is used in wall panels or wall and / or ceiling linings. The extent of involvement of the insulant, amongst other factors, is dependent on the failure pattern of the protective facings. With good design and careful selection of protective facings, the rate at which the insulant subsequently contributes heat, smoke, etc. to fire development inside an enclosure can be effectively reduced; the time to involvement can also be substantially delayed^(11, 12).

A large scale experimental research programme conducted by the Building Research Establishment (BRE) in England, simulating the effects of a fully developed room fire over a large area of externally insulated masonry assemblies, has identified the design features affecting their fire performance⁽¹³⁾. Where expanded polystyrene sheeting is used, by careful selection of the protective weathering finish, with suitable design and installation of its support and correct installation around reveals, together with appropriate fire barriers, it is possible to reduce effectively the contribution made by an insulant to progressive vertical fire spread over the external finish or through the insulant / cavity; the extent of fire damage can also be limited. The fire performance of homogeneous lightweight renders containing expanded polystyrene beads as aggregates applied externally to solid masonry walls has been shown to be satisfactory.

The smoke particles produced in a flaming fire are large, black and irregular in shape. The density of the smoke produced increases with increasing temperature and with the intensity of the heat flux onto the material. In a smouldering fire, e.g. where the expanded polystyrene materials remain effectively protected and decomposition occurs in oxygen deficient conditions, small spherical grey particles predominate and the specific optical density values are lower than for flaming conditions.

When exposed EPS burns, it generates a considerable amount of heavy, dense, black smoke, which is usually proportional to the mass consumed by the fire. It is sometimes argued that the toxicity of the smoke fumes will be in proportion to the density of the smoke but this appears not to be the case.

For applications where EPS is used without a protective

facing, the amount of smoke is limited by the favourable mass to surface area ratio of the low density foam. Although, exposed burning EPS in its standard design produces a lot of smoke, the total quantity of smoke is small due to the low density of EPS. But given that EPS in virtually all cases is not used in an exposed form or in rooms without any risk of fire and is sandwiched between other materials, it is more realistic to assess smoke production in these practical situations. Normally, EPS is protected from the fire by the surrounding materials and it will only catch fire, when the whole of the building is ablaze. In these cases, the EPS will contract due to the heat, but does not ignite and does not contribute to the propagation of the fire and the amount of smoke may be limited. The production of smoke is also therefore accordingly small. Consequently it can be concluded that EPS, when used correctly in recommended applications, does not lead to an increased risk of smoke density³.

Toxicity

As discussed earlier it is difficult to predict the behaviour in real fires from small-scale tests. The same considerations apply to assessing the hazards of gaseous emissions from burning materials. In practice, two approaches are followed; firstly, the determination of thermal decomposition products and, secondly, studies of their biological effects. It is necessary to combine the two approaches to obtain a realistic overall estimate of the hazards.

Although burning EPS gives off black smoke, the toxicity of the released smoke fumes is considerably less than those of other commonly used materials. This was already concluded in 1980 by the TNO Centre for Fire Safety¹⁴ for both EPS in its standard design and EPS to SE quality. The toxicity of fumes was measured for wood, wool, silk, cotton, fire retardant treated cotton and three sorts of EPS (see table). In the case of EPS the toxicity of the smoke appeared to be considerably smaller than that of the other materials.

Extensive research into the toxicity of smoke fumes from burning EPS has also been conducted in accordance with the DIN 53436 method which is a small scale combustion toxicity test, which gives results of relevance to full scale fires.

In this test samples are heated respectively to 300, 400, 500 and 600° C. As well as various types of EPS, individual natural products such as pine wood, chipboard, expanded cork and triplex, rubber, felt and leather were also studied³. The results are summarised

in the table below. The smoke fumes from EPS appeared at most to be equally toxic as, or less toxic than those from the natural products throughout the whole of the range. EPS itself scored very well based on equal volumes of the test samples, due to the extremely low density and light weight of EPS (98% air). In addition, no negative effect on smoke development from the fire retardant was found in EPS-SE.

The table shows that significant amounts of carbon monoxide and styrene monomer are given off when EPS is burnt. Their relative toxicity can be estimated from the figures for their acute inhalation-toxicity value (L/C₅₀ inhalation period 30 min) of 0.55 % v/v for carbon monoxide and 1.0 % v/v for styrene. Thus, the acute inhalation toxicity of styrene is less than that of carbon monoxide, and its concentration in the EPS composition products is also less at elevated temperatures found in a fire. Carbon monoxide can be fatal if inhaled for 1 min. to 3 min. at concentrations of 10 000 p.p.m. to 15 000 p.p.m. Styrene has an odour which can be detected at 25 p.p.m. to 50 p.p.m. and which becomes intolerable at between 200 p.p.m. and 400 p.p.m. This warns of the necessity of immediate evacuation of an area. Eye irritation and nausea may occur at 600 p.p.m. and some neurological impairment may occur at 800 p.p.m. In a fire the styrene is likely to be further decomposed to form carbon monoxide, carbon dioxide and water.

The toxicity of smoke fumes from EPS in various 'natural' materials.

Sample	Smoke gasses in a Fire	Emitted fractions (v/v) in ppm at different temperatures			
		300 °C	400 °C	500 °C	600 °C
EPS (standard grade)	Carbon monoxide	50*	200*	400*	1,000**
	Monostyrene	200	300	500	50
	Other aromatic compounds	fractions	10	30	10
	Hydrogen bromide	0	0	0	0
EPS-SE (fire retardant grade)	Carbon monoxide	10*	50*	500*	1,000*
	Monostyrene	50	100	500	50
	Other aromatic compounds	fractions	20	20	10
	Hydrogen bromide	10	15	13	11
Deal	Carbon monoxide	400*	6,000**	12,000**	15,000**
	Aromatic compounds	--	--	--	300
Chip board	Carbon monoxide	14,000**	24,000**	59,000**	69,000*
	Aromatic compounds	fractions	300	300	1,000
Expanded cork	Carbon monoxide	1,000*	3,000**	15,000**	29,000**
	Aromatic compounds	fractions	200	1,000	1,000

* smouldering/glowing ** as a flame -- not detected

Remarks: Test conditions specified in DIN 53 436; air flow rate 100 l/h;
300mm x 15mm 20mm test specimens compared at normal end-use conditions

For SE grades, traces (10 - 15 ppm) of hydrogen bromide were detected by the DIN 53 436¹⁹ method. The LC₅₀ value of HBr is similar to that of carbon monoxide. Since its concentration is so low, relative to carbon monoxide, its presence in the fumes given off from burning SE grade EPS does not add significantly to the health hazard. Owing to the small amounts of HBr generated, no significant corrosive effects are expected.

Combustion of SE grade EPS under the conditions prescribed in DIN 53 436 yields no traces of brominated dibenzodioxins, either in the gaseous phase or in the solid residue, only negligible proportions of brominated dibenzofurans, none of which are a toxic substance as defined in of the (German) Prohibited Chemicals Order 1994.

The contribution of pentane

Pentane is used as the blowing agent to expand polystyrene into EPS. It is a pure hydrocarbon which although flammable migrates from the EPS end product within a short period of time after manufacture. Furthermore, Pentane is unstable and decomposes in the atmosphere into carbon dioxide and water within a few hours. Pentane therefore does not play any significant part in the subsequent fire properties of the EPS or have any role in the occurrence and development of a building fire.

The conclusion from all of the studies is clear and conclusive: less toxic gases and fumes are released during the combustion of EPS in both its standard design and to SE quality than is the case for the combustion of 'natural' materials such as wood, wool and cork and than is the case for most plastics.

Melting and droplets

As has been stated earlier, EPS should only be used protected when in a room with any risk of fire. In agricultural buildings EPS coated with thin aluminium foil is frequently used; attaching these plates is critical for the occurrence of hot droplets of molten polystyrene (In some countries, such as Denmark, this application is illegal. Here, the SE grade should always be used). For this reason, the relevant manufacturers specify working regulations and conditions of use. In addition it is definitely a factor in the occurrence of fire that equipment, which may possibly generate sparks or fire in the event of a defect, must be kept at a safe distance (thus never in direct contact). Only then is fire safety enhanced and the chance of droplets of molten EPS considerably reduced; in each case for agricultural buildings the possibility of removing "the livestock" becomes much less!

Fire residues of EPS and disposal – Cleaning a building after a fire.

The emissions given off and the residues remaining when EPS (with and without flame retardant) is burnt do not present any particular danger to the environment⁹. Extinguishing water resulting from EPS fires and fire residues can be disposed of without any special treatment in municipal installations for sewage and solid waste, respectively.

In most fires, a large number of materials are involved. After a fire with EPS, the building should be cleaned as follows:

1. Remove dust and soot by means of dry vacuum cleaners, assisted by mechanical brushing.
2. Grit-blast porous surfaces such as concrete.
3. Wet clean when procedures according to 1 and 2 are insufficient, for instance with alkaline detergent solutions. Residues from the cleaning operations should be collected and disposed of by incineration; the recommended minimum temperature to operate the incinerator is 850°C. This work should preferably be done by companies specialised in this field.

Protective coverings

As previously discussed EPS, like most plastics, is flammable. As a standard rule EPS should never be installed 'unprotected', if a room has any risk of fire. When EPS insulation has been professionally installed it will only catch fire, in the case of a building fire, if the materials surrounding it are already burnt or collapsed. This means that the building and its contents were already ablaze before the fire reached the EPS. It is only as a result of indifference, ignorance or carelessness that EPS should catch fire at the start of a fire. One area of application that, for example, is often 'under fire', is the flat, insulated roof. Yet it has been shown, that with a good design, incorporating compartmentalisation, detailed planning, and a careful implementation to ensure that preventative measures are taken, a fire-safety roof using EPS insulation can be made without difficulty.

It is therefore recommended that installed expanded polystyrene boards should always be covered by a protective facing, suitably fixed to prevent collapse in the event of fire. Protection of the surface of expanded polystyrene with 9 mm thick plasterboard or plaster of minimum 10 mm has been shown to provide resistance to ignition, if the protective facing is mechanically supported. An unsupported coating, applied directly on the expanded polystyrene materials, with adequate insulation to maintain the interface temperature below 100°C for a specified time will provide protection, as long as the integrity of the facing is preserved. Thin finishes, such as plaster skim coat, aluminium film, flame retardant paints or intumescent coatings applied directly on to the expanded polystyrene materials can delay ignition to a limited extent, but once the underlying material softens under the effect of heat, penetration and progressive failure of the coating may occur.

General precautions for storage of EPS on Site.

As discussed earlier under certain circumstances, expanded polystyrene materials can be ignited readily by exposure to a naked flame. Care should be taken to avoid contact with such sources of ignition when handling and storing the material before and after installation. Fire-retardant grades are available for use where appropriate, and particularly to take account of spread of flame requirements. In regard to the generation of dust during the production and processing of EPS, eg by mechanical treatment of the foam, the same safety procedures must be observed as generally for dust of other organic materials.

Conclusions

EPS is flammable, as is the case with so many other building materials. However, this is only relevant if you assess EPS as an exposed insulating material. Fortunately, the fire safety philosophy in the European Union has been developed on the basis of or for the purpose of assessing structures or products 'in end use conditions'. There will therefore be performance requirements stipulated in relation to the complete building element.

It is strongly recommended that expanded polystyrene should always be protected by a facing material, or by complete encapsulation.

Taking these factors into consideration it can be concluded that expanded polystyrene products do not present an undue fire hazard or lead to an increased risk of smoke density when installed correctly in recommended applications.

We have also gone into some detail on the nature and characteristics of the material EPS. We have demonstrated that, in terms of toxicity in the event of fire or combustion, this plastic scores just as well as or better than natural products, such as wood, flax, jute, etc..

In summary: It is possible to build ensuring fire safety using EPS!

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