

2. BEHAVIOUR OF EPS IN CASE OF FIRE

The purpose of this chapter is to clearly quantify the fire performance of expanded polystyrene (EPS) when used as an insulation material in buildings. This chapter 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 modeling real fire situations from scaled tests.

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 realize that the assessment thereof is 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 condition and specific application.

Thus the important factors which must be considered in determining the potential fire hazard of EPS are:

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

2.1 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 building 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 localized 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 flashover 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.

2.2 THE BEHAVIOUR OF EPS IN A FIRE

Similar to 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 flame-retardant modified quality, designated by the code “FR”. Flame retarded FR grades as specified by EPSASA, which make the expanded material much more difficult to ignite, considerably reduce rates of spread of flame.

In South Africa EPSASA recommends that FR grade be used. However, in many 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).

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 (FR Grade). The transfer ignition temperature is 360°C. In the case of EPS- FR, 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 easy 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.

2.3 FIRE-RETARDANTS

The presence of fire retardant additives in EPSASA FR 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, EPSASA FR grades will eventually burn, reflecting the organic nature of polystyrene. In such instances the building is usually beyond the point of rescue.

EPS-FR grade contains a small quantity of fire-retardant agent (max. 0.5%). This is normally 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 furans 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 polybromodibenzofurans and –dioxins when using different types of combustions over a temperature range of 400 to 800°C. The same result had previously been concluded by the Dutch Ministry for the Environment 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 Institute itself showed that in the HBCD itself there were no brominated dioxins or furans to be demonstrated. Recent research at the Karlsruhe 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 water.

2.4 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 uses 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.

RESULT FROM HEAT RELEASE TEST FOR EPS FOAM (ISO) 5660; cone calorimeter)			
Fire parameter	Flux (kW/m²)	EPS Regular	EPS FR
Time to ignition (s)	20	N1 ¹⁾	N1
	30	73	77
	40	28	40
	50	18	24
Mean peak rate of heat release (kW/m ²)	20	N1	N1
	30	299	238
	40	394	321
	50	407	379
Mean effective heat of combustion (MJ/kg)	20	N1	N1
	30	27	27
	40	28	26
	50	28	27
Mean rate of heat release from ignition time to 60 s (kW/m ²)	20	N1	N1
	30	146	168
	40	173	153
	50	158	173
Mean rate of heat release overall (kW/m ²)	20	N1	N1
	30	214	93
	40	228	110
	50	209	119
Mean specific extinction area ²⁾ (m ² /kg)	20	N1	N1
	30	1317	1461
	40	1200	1334
	50	1346	1297

1) N1 = no ignition under stated flux conditions

2) Smoke density expressed as mean specific extinction area (SEA)

No flaming ignition was observed at a heat flux of up to 20kW/m^2 . For higher heat fluxes, the overall rate of heat release (RHR) and peak RHR were lower for FR grades 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/m^3 to 1250 MJ/m^3 compared with 7150 MJ/m^3 to $10\,400\text{ MJ/m}^3$ 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.

The extent and rate of heat release is limited primarily by ventilation. For example a foam density of 16 kg/m^3 requires over 150 times the volume of air to achieve complete combustion. This is unlikely to occur, so its full potential heat is rarely released.

A 200mm-thick layer of EPS with a density of 20kg/m^3 represents the same amount of energy as a 17mm-thick layer of pine wood. But who hesitates to use 17mm-thick pine as an unprotected surface on a ceiling or wall?

2.5 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.

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 optimal 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. 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 density.

2.6 FLAME SPREAD

Flame spread is a process of progressive ignition along a continuous surface. The extent and rate of flame spread depends 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 localized 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.

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.

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. Where expanded polystyrene sheeting is used, by careful selection of the protective weathering finish, with suitable design and insulation 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.

2.7 TOXICITY

As discussed earlier it is difficult to predict the behaviour in 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 Safety for EPS in both standard and FR grades. 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 studied. The results are summarized in the table below. The smoke fumes from EPS appeared to be less toxic, or at most equally toxic to 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 lightweight of EPS (98% air). In addition, no negative effect on smoke development from the fire retardant was found in FR grades of EPS.

The table shows that insignificant amounts of carbon monoxide and styrene monomer are given off when EPS is burnt.



2.9 FIRE RESIDUES OF EPS AND DISPOSAL

CLEANING AND 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 environment. 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.

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 surface such as concrete.
3. When procedures according to 1 and 2 are insufficient, then alkaline detergent solutions can be used. 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 specialized in this field.

2.10 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, e.g. by mechanical treatment of the foam, the same safety procedures must be observed as generally for dust of other organic materials.