Polyurethane foams. What happens when they burn?

Technical Information

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The public reacts with increasing sensitivity to the health risks which may arise for example from the inhalation of combustion gases. But possible risks can be estimated. The studies show that the risk to affected parties is largely independent of whether natural or synthetic materials are involved.

If identical volumes of wood, leather, PUR foam and wool are burned in the standardised laboratory test, then the harmful-substance potential of the foam is comparable to that of wood, but less than that of burning leather and felt.

At the same time the influence of the nature of the flammable material on the overall risk of a fire is limited. Wind conditions, temperature, the spatial environment of the fire and the processing of the flammable material into the finished product are far more influential. These factors are determined in additional tests under real conditions. A combination of laboratory and practical tests is therefore indispensable.

All known results from both series of tests also indicate that, in the event of fire, no product-specific critical harmful-substances are released from goods in store and commercial products made of PUR rigid and flexible foams, which result in increased health risk relative to fires involving other synthetic or natural substances. Nevertheless a check on the fields of application of foams for possible risks is always recommended. Specific examples are given below.

The consequential products of fire: heat, gases, water and solids

The consequential products of fire (smoke) form a mixture of gases, water and solids (soot). The fire consumes oxygen, which is not then available for breathing. Soot settles on the skin. Smoke is inhaled, obstructs escape, spreads due to wind and updraught and pollutes, diluted by the ambient air, even areas some distance from the fire.

The combustion gases are generally colourless and odourless. Inhaled at high concentration, they can lead to death. This does not apply, though, to the solid black soot particles. The colour of the smoke, therefore, does not tell us anything about its acute toxicity. But soot should still neither be inhaled nor allowed to remain on the skin. Substances which could cause damage with lengthy contact adhere to its surface. In case of fire, protection against soot is provided by holding wet cloths in front of the mouth and nose, and by subsequently cleaning the contaminated areas with the usual means. Solid residues at the source of the fire are to be rated as for soot. The disposal method recommended by the German Federal Office for the Environment is incineration at hazardous waste disposal plants (Federal Gazette 1/1990). This recommendation applies irrespective of the material burned.

The reaction product water occurs in aerosol or vapour form. It contains dissolved gases and has the character of an acid. Water condenses on cool surfaces, is absorbed by rain and finds its way into water used for fire-extinguishing. The latter also absorbs combustion gases, extracts residues and collects harmful substances. Fire-extinguishing water should not therefore be allowed into surface waters or the drains without testing. Injury to persons may be ruled out since as a rule only experts in protective clothing come into contact. Analyses by the University of Wuppertal have indicated that fire-extinguishing water from fires involving PUR foams does not contain more than the usual level of harmful substances[1]. Environmental damage may also be caused by extinguishing media used by the Fire Brigade.

Any acute risk in the case of fire therefore stems only from the heat, the lack of oxygen and the combustion gases. Statistics confirm that fire victims due to heat are rare. The lack of oxygen plays a role only in fires in enclosed spaces. On the other hand more than 3/4 of victims die from poisoning through combustion gases; these are produced equally by small, low-temperature fires without flames and heat, and are fatal under corresponding framework conditions to those applying inthe case of major fires.

Combustion gases: relevant constituents and maximum concentration

All combustible substances contain carbon and hydrogen, often oxygen, and sometimes nitrogen, sulphur, chlorine, bromine and phosphorus. These elements are oxidized by oxygen - this is how a fire is defined in chemical terms - and form gases: carbon dioxide, water, nitrogen oxide, sulphur dioxide, phosphorus oxide, hydrogen chloride and hydrogen bromide. The reaction proceeds at different rates depending on temperature build-up and oxygen supply. Fires always suffer from oxygen deficiency, so that oxidation is not complete. Carbon monoxide and material-typical breakdown products are also produced, e.g. hydrogen cyanide (hydrocyanic acid), amines, styrene, formaldehyde or acrolein. From the toxicological standpoint these are the most important gases among many others.

However the simple existence of these gases in the smoke is not sufficient for an estimation of risk. More important is how much is produced and how quickly. All gases contribute proportionately and cumulatively to the toxicity of the smoke - but at different rates depending on their inherent toxicity. The relationship between volume and toxicity leads to the result that in practice only carbon monoxide and more rarely hydrogen cyanide dominate the harmful-substance potential of the smoke: carbon monoxide because it always occurs in large amounts due to the frequency of carbon in the combustion material; hydrogen cyanide, which occurs only rarely and in small quantities, because it is highly toxic. Both components form at virtually the same time.

The gas mixture becomes fatal only when the concentration of one gas alone or of several gases pro rata exceeds a limit value in the air inhaled in breathing. Here it is of secondary importance whether this limit value is exceeded by carbon monoxide alone or through the combined effect of several gases. Statistics of fire victims confirm that in over 90 % of cases, carbon monoxide is the sole cause of death. A major contribution from hydrogen cyanide is rare (4 %) [2].

PUR foams contain mainly carbon, hydrogen, oxygen and < 10 % nitrogen. In the combustion gas we therefore find carbon dioxide, carbon monoxide and water as the main constituents, together with oxidation products and hydrogen cyanide in low concentration. Halogen compounds may be ignored since the foam generally contains amounts of less than 0.1 % by weight. While it is true that the use of halogenated flame retardants increases the halogen content of the foam, this does not significantly alter the balance of the consequential products of the fire.

Standardized laboratory tests

Since the external influences on real fires vary, they must be standardized in testing, in order to make possible the evaluation of the harmful-substance potential of various products in the smoke. The evidence described above has therefore been obtained in numerous laboratory tests under constant, comparable parameters. The most important German standard here is DIN 53436. It permits relative comparisons of product characteristics at different temperatures and with differing volumes of air, corresponding to different fire situations. Specimens, of equal volume, of PUR rigid and flexible foam here form decomposition products which have a harmful-substance potential equal to that of burning wood materials, and below that of felt and leather under defined fire scenarios (see Table).

Whereas the combustion gases produced from wood act through their carbon monoxide content, with PUR foam there is a combined action of carbon monoxide and hydrogen cyanide. The influence of varying fire conditions and the differing nitrogen content of the compared products lead to a varying composition of the combustion gases. With a marked lack of oxygen, the hydrogen cyanide content of the combustion gas rises. For wool and leather, relevant amounts are measurable at just 300 °C, while for PUR foams this occurs only in the range 500 – 600 °C. If on the other hand there is an adequate supply of oxygen, the hydrogen cyanide concentration generally falls from 600 °C onwards. The molecule is thermally destroyed or oxidised, since hydrogen cyanide is combustible and is more labile than carbon monoxide.

Practical tests supply realistic results

Owing to the impossibility of simulating all the circumstances of a real fire in laboratory testing, which can be used only for relative product comparisons, practical tests are indispensable. In the laboratory test for example the rate of burning of the combustible material, i.e. the weight burned per unit of time, is held constant - but this does not happen in practice. The rate of burning is critical for the speed with which the limit concentration of toxic gases in the inhaled air is reached. The special features of the finished commercial product, its design, its surface, its moisture content or its combination with other materials are factors not taken into account in the laboratory test, although all of them alter the course of the fire, thereby also varying the overall risk. Application-oriented practical tests on the real scale and comparative laboratory tests must therefore complement one another.

In real practical tests the International Isocyanate Institute has compared the fire behaviour of upholstered furniture with PUR foam with that of conventional furniture. Here the relationship between the harmful substances produced and the rate of burning was demonstrated[3]. Cushions with PUR standard flexible foam and latex with readily-combustible coverings burned more quickly than cushions with flock of wool. By using suitable coverings or intermediate layers which inhibited burning, it was possible with both cushion materials not only to delay the build-up of toxic gases, but also to reduce their concentration and thereby minimise the potential risk. In other studies it was observed[4] that the risk threshold from the gases was reached only when the temperature and lack of oxygen in the living space were already life-threatening. This finding is critical in view of the use of upholstered furniture in enclosed spaces, in which the prevailing framework conditions are different from those relating to fires in the open air.

Experience of fires

Additional information on actual risks is supplied by the comparison of test results with data from real fires. According to the experience of the Boston Fire Brigade relating to harmful substances in the atmosphere from fires in the open air, hydrogen cyanide and nitrogen oxide are not observed in critically toxic amounts in the combustion gases[5]. This is understandable in the light of the findings referred to above, and may be explained by the oxidation of hydrogen cyanide, also the effects of dilution by the surrounding air. The report supports the results of independent major fire tests, according to which there are no exceptional product-related risks from polyurethane foams in fires.

Investigations of fire victims in house fires in England[6] revealed enhanced hydrogen cyanide concentrations in individual cases. These can be verified by analysis, if e.g. house fires create an increased risk to human life due to low exchange of air and an increased rate of combustion due to the framework conditions of the fire. The product-comparison laboratory tests are thereby indirectly confirmed since they show that the toxicity of the smoke when inhaled may be due to the existence of one or more critical combustion gases, without there being any significant change in the harmful-substance potential of the product as compared with other materials.

Toxicological results for decomposition products of polyurethane flexible and semi-rigid foams in accordance with DIN 53436 (after Kimmerle and Prager [8, 9])

Material: Coverage by weight	Airflow (L / h)	Temperature (°C)	Mortality
PUR 3 (semi-rigid) 0,12 g / cm	100	400 500	2 / 20* 0 / 20*
PUR 4 (flexible) 0,12 g / cm	100	400 500	3 / 20* 20 / 20
PUR 5 (flexible) 0,12 g / cm	100	400 500	0 / 20* 2 / 20*

*all surviving animals showed symptoms

Tocicological resuts for decomposition products of polyurethane rigid foams in comparison to pine wood and wool in accordance with DIN 53436 (after Kimmerle and Prager [8, 9])

Material: coverage by weight	Airflow (L / h)	Temperature (°C)	Mortality
Pine wood 0,12 g / cm	100	400 500	12 / 14 10 / 20
PU-rigid FR 0,12 g / cm	100	400 500	0 / 14 20 / 20
Wool 0,12 g / cm	100	400 500	2 / 20* 20 / 20*

*all surviving animals showed symptoms

Toxicological results for decomposition products of semi-rigid polyurethanes in comparison with leather and felt in accordance with DIN 53436; specimens of equal volume
(after Hoffmann and Sand [7])

Material	Airflow (L / h)	Temperature (°C)	Mortality
PU-rigid	100 100 100 100	300 400 500 600	0 / 12 0 / 12 12 / 12 12 / 12
Leather	100 100 100 100	300 400 500 600	0 / 12 12 / 12 12 / 12 12 / 12
Felt	100 100 100 100	300 400 500 600	7 / 12 12 / 12 12 / 12 12 / 12

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