CAUSES AND PROCESS OF FIRE

Rigid PVC-U Cable Management Systems

Summary

PVC-U offers many key benefits and is an ideal material for fire prevention:

- **Fire prevention is the key objective and PVC-U materials outperform many other plastic materials in this respect.**

- **PVC-U is inherently flame retardant and requires an external heat source to continue combustion.**

- **PVC-U has a low heat of combustion and a low burning rate. Hence PVC-U contributes significantly less to heat release and fire propagation than many other materials.**

- **When subject to a fire situation, a low rate of smoke production is generated by PVC-U during the critical early stages of a fire when personnel evacuation is most likely.**

- **If PVC-U is present in isolation, without any other combustible materials, the high fire retardancy of PVC-U will prevent the propagation of the fire.**

- **PVC-U forms an effective barrier to flame spread, making a minimal contribution to fire development and growth. Low total flame spread and low rate of flame spread are highly desirable as they govern the overall size of the fire.**

- **Burning PVC-U chars and is self-extinguishing. It does not produce flaming droplets or burning debris, both of which are a major cause of flame spread. The presence of PVC-U therefore ensures that the ignition of adjacent products is less likely.**

- **Charred PVC-U consists of an expanded carbonaceous structure which protects the underlying material.**

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Frequently Asked Questions

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What is PVC?

Unplasticised or rigid PVC (PVC-U) products are tough and resistant to weather and corrosion. Typical applications are pipes for water, drainage and sewerage, rainwater goods, electrical trunking, conduit and ducting, wall cladding, furniture components, window frames and signs.

Plasticised or flexible PVC (PVC-P) products have a wide range of flexibility, softness, elasticity and abrasion resistance. Typical applications of PVC-P are in cable insulation and sheathing, flooring, wall coverings, furniture upholstery, coated fabrics, medical devices and moulded-on plugs.

PVC-U is a material that contributes little to the spread of the fire and can therefore be less hazardous than a material that contributes more to the fire spread, even before taking into account a comparison of smoke density and fire gas toxicity.

Plasticized PVC (PVC-P), that is used for cable insulation for example, is easier to ignite and burns more easily than PVC-U because of the presence of the plasticizer**.**

Conduit and Trunking

PVC-U has been the first choice plastics material for electrical conduit and trunking products for many years. In common with pipe and rigid sheet applications, conduit and trunking products made from PVC-U do not contain plasticisers, are highly resistant to ignition and act as effective barriers to flame spread from malfunctioning electrical components contained within them.

If PVC-U conduit or trunking is involved in a fire originating elsewhere in the installation, its resistance to ignition and low rate of heat release means that it makes a minimal contribution to fire development and growth.

The PVC-U materials used to produce conduit and trunking have been tested for ignitability to BS 476 Parts 5 and 12, and for flame spread to BS 476 Part 7, when a Class 1 rating was achieved.

Background

Many factors should be taken into account when assessing fire risks. For example:

- Time to ignition
- Burning rate
- Heat release
- Smoke production
- Toxicity

Escape time is a critical factor in any fire scenario. Therefore materials with the following characteristics maximise the chance of survival in a fire since they allow people to escape before being overcome by the fire:

- Difficult to ignite
- Low burning rate
- Low heat release
- Low smoke production
- Low toxicity

Un-plasticized (rigid) PVC-U that is used in cable management systems has all these characteristics during the important early stages of a fire.

The toxin that is of major concern during any fire is carbon monoxide which is produced in almost any fire from the burning furniture, furnishings, paper etc., especially in conditions of low ventilation. Other toxins may be produced depending on the chemical nature of the fuel and the stage of the fire. These include sulphur dioxide, nitric oxide, nitrogen dioxide, hydrogen cyanide, acrolein, hydrogen fluoride, hydrogen chloride, and hydrogen bromide. It is therefore important to avoid materials that produce these toxins in the early stages of a fire.

There are materials that, when burned, produce acid-gas but produce only limited amounts of highly toxic gases, due to a low rate of burning. Un-plasticized (rigid) PVC-U that is used in many cable management systems has these properties.

PVC-U has a low rate of smoke production during the early stages of a fire. This is because it contains chlorine which, like all halogens, is an inherent flame retardant which inhibits sustained burning.

The terms "halogen free", "low smoke and fume (LSF)" and "low acid-gas" do not equate with low fire hazard. For example:

- Petrol, Napalm and TNT are all "halogen free"
- Polyethylene is "halogen free" but it behaves chemically in a fire as a solid form of petrol
- Hydrogen is a dangerously flammable and potentially explosive gas but when it burns it produces no smoke or fume (the only product of combustion is water)
- Fluorinated polymers (e.g. PTFE) produce acid-gas when they burn but are extremely difficult to ignite, making them ideal for use in aircraft electrical wiring.

Introduction to Fire Testing

There are two types of fire test – f**ire resistance** tests and **reaction-to-fire** tests.

Fire resistance tests are used to assess the effectiveness of fire barriers which are used to prevent the spread of fire.

Reaction-to-fire tests measure what happens to products and materials when they are exposed to heat or flame.

The fire performance parameters assessed by reaction-to-fire tests can be grouped into the following categories:

Ignitability: A measure of the ease with which a test specimen can be ignited by heat or flame, such that combustion can be sustained.

Flame Spread: Once a test specimen has been ignited, flame spread tests measure how far and/or how quickly flames spread over the test specimen.

Heat Release: Burning is an exothermic reaction, i.e. it releases heat. The rate at which a test specimen releases heat, and the total heat released, are crucial factors which influence overall fire size and growth rate.

Smoke opacity: Virtually all burning materials release smoke, which may hinder escape from the fire, and fire fighting, by obscuring visibility. The rate of smoke release may be more important than the total potential smoke release, because smoke generated early in the fire is a key factor in hindering escape.

Toxicity of fire gases

Fires produce toxic gases. They can be divided into three types – **asphyxiants, irritants** and **carbon dioxide**:

Asphyxiants: Carbon monoxide is the most significant asphyxiant and is particularly dangerous because it has no taste. Hydrogen cyanide is also an asphyxiant. The toxic hazard is calculated from two factors: the inherent toxicity (toxic potency) and the dose to which a victim is exposed (concentration multiplied by exposure time).

Irritants: Most other fire gases act as irritants. Their hazard is calculated from the toxic potency and the concentration of the gas.

Carbon dioxide: Carbon dioxide is a major product of almost all fires. Its effect, above a volume fraction of about 2%, is to make victims breath faster and so it increases the dosage of other fire gases received in any given time period. This increases the severity of the consequent effects. However, in many fire scenarios the 2% threshold is not reached.

Corrosivity of fire gases

Many materials can generate fire gases which may corrode metal surfaces, but the level of corrosion observed depends on numerous factors, eg the chemical nature of the fire gases, the nature of the substrate, the concentration of the fire gases, the time of exposure, temperature, humidity etc.

Fire hazard assessment

It is worth noting that many of the fire tests in use today have been developed to assess only one fire parameter, very often judging the results on a pass/fail basis. The pass/fail criteria are usually selected to discriminate between classes of materials or products, to satisfy a particular application or regulatory need. Pass/fail tests **cannot** be used to quantify fire hazard.

When considering the overall fire hazard of a material or product it is therefore always essential to consider all its reaction-to-fire properties in the fire scenario of concern. If a single property is highlighted the hazard assessment will be incomplete and may be seriously flawed.

The fire performance of PVC-U in reaction-to-fire tests

Flame spread

Flame spread tests provide data on how quickly a specimen burns once it has been ignited and sustains combustion. Clearly low total flame spread and low rate of flame spread are highly desirable as they govern the overall size of the fire and are key factors in determining the hazard from smoke, corrosive and toxic gases. PVC-U inhibits the spreading of flame.

The Underwriters Laboratories vertical flame spread test, UL 94V, is widely recognised and PVC compounds achieve a high (94V-0) rating. The relevant British and international standards are BS 2782 Part 1 Method 140A:1992 and its ISO equivalent, ISO 1210:1992. PVC compounds usually show a burn distance of less than 25mm and a rate of flame spread of less than 50mm per minute.

Flame spread test requirements are also included in most national building regulations and many PVC-U grades qualify for the best classification. In the UK, for example, BS 476 Part 7 is used as a qualifying test for applications such as wall coverings and lining boards. The performance of PVC-U in this test depends on the formulation and whether the test specimen is sufficiently well supported in the specimen holder.

The International Maritime Organisation (IMO) introduced a lateral flame spread test to classify the fire characteristics of bulkhead, ceiling and deck finish materials for shipping. This test is now widely used as ISO 5658 Part 2:1996. A test specimen is placed in vertical position adjacent to a gas-fired radiant panel where it is exposed to a defined field of radiant flux. PVC-U products show low flame propagation on this test.

Frequently asked questions:

What is meant by 'Fire'?

A fire is an uncontrolled thermal process. It results from the interaction of three necessary and sufficient factors:

- Presence of combustible material
- Presence of oxygen from the air
- A source of sufficient heat

If these three factors occur in specific proportions, the thermal degradation process starts (fire ignition). The combustion increases the temperature of products located close by, which also ignite when they reach a certain temperature. The fire then spreads.

Combustion destroys partly or completely the structure of the burning materials. In addition to the production of fire gases this can lead to the formation of:

- Flaming droplets
- Burning debris or embers
- Inert debris, such as ashes and charred material

Another key factor is the remaining structure of the burning material. Most combustible products yield powdered ashes and very often also volatile matter, which do not protect the underlying material from the fire.

What are the key factors that need to be considered?

The main hazards from fires are:

- Thermal effects, essentially close to the fire
- Fire gases, the effects of which reach a much wider area than the heat

The thermal effects result from temperature and radiation. They are directly proportional to the size and development of the fire, which are themselves directly proportional to the combustible load present in the affected space. They are the main cause of destruction of equipment inside buildings and can result in the most severe cases to the partial or total destruction of the building's structure. The thermal effects are closely linked to the fire behaviour of the materials present: ease of ignition, heat production, flame spread.

Fumes and gases affect people in the following ways:

- Lowered visibility due to smoke, which impairs escape
- Toxic effects which can reduce psychomotor ability, incapacitate or even kill.

These effects result from the type of gases released, but of course also from the speed at which the fire is spreading and at which the materials are degraded. A material that contributes little to the spread of the fire can therefore be less hazardous than a material that contributes more to the fire spread, even before taking into account a comparison of smoke density and fire gas toxicity.

What are the positive factors when considering the fire performance of PVC-U products and why should I consider using PVC-U materials in buildings?

PVC-U offers several key benefits in the fire process:

- If used in isolation, without the presence of any other combustible materials, PVC-U is extremely difficult to ignite and will not propagate a fire. Fire prevention is the key objective and PVC-U materials outperform many other plastic materials in this respect.

- The presence of over 50% halogen makes it difficult to ignite even in the absence of any additional flame retardant.

- It has a low heat of combustion and hence contributes less to heat release and fire propagation than many other materials.

- Burning PVC-U chars, does not produce flaming droplets or burning debris, both of which are a major cause of flame spread. Presence of PVC-U therefore renders the ignition of adjacent products less likely.

- Charred PVC-U consists of an expanded carbonaceous structure which protects the underlying material.

How important is hydrogen chloride production?

When PVC burns, the chlorine in it is converted to hydrogen chloride gas. Concerns about PVC in fires are mainly linked to the release of this hydrogen chloride (HCl), which is classified as a “toxic irritant” by ISO. However, all burning materials release toxic gases, the main one being carbon monoxide (CO), which is classified as a “toxic asphyxiant” by ISO. Fire gases from other materials can be as toxic or more toxic than those from PVC. The majority of people who die from exposure to toxic gases have inhaled lethal levels of CO as evidenced by blood analyses. It is also important to note that CO is odourless and hence kills without warning. The irritation caused by HCl has a warning effect at levels far below levels that may cause death. For instance, before the advent of modern heating systems, many people died in their sleep from CO poisoning, but experiments have shown that it is impossible to continue sleeping when HCl is present, even in harmless concentrations.

HCl will dissolve in water to form hydrochloric acid. This can have a corrosive effect and may therefore contribute to the damage to buildings and their contents. However, in most instances this damage is dwarfed by the direct effects of the fire and the damage caused by fire-fighting.

Does PVC-U contribute to the spread of fire?

PVC-U does little to contribute to the spread of a fire. It is less hazardous than a material that contributes more to the fire spread. The PVC-U used for the manufacture of cable management systems is flame retardant to BS 476 Part 7 Class 1.

APPENDIX

Definitions of the key terminology – smoke, halogens, toxicity, flammability, survivability etc:

Question: What is a **“halogen”?**

Answer: The halogens are the following group of chemical elements:

- **Fluorine**
- **Chlorine**
- **Bromine**
- **Iodine**
- **Astatine (N.B. extremely rare and radioactive)**

They are almost never found in their elemental form, but occur as compounds.

In everyday life we are most familiar with fluorine as a constituent of chemicals added to drinking water and to toothpaste in order to prevent tooth decay, and in non-stick coatings.

Chlorine is probably most well known as a constituent (61% by mass) of common salt, sodium chloride. Some other familiar chemicals which contain chlorine are the disinfectant TCP (trichlorophenol) and bleach (sodium hypochlorite). Chlorine is also added as a disinfectant to our drinking water and to swimming pools.

Bromine is less familiar. It is widely used in the form of silver bromide in photography, although less so these days, with the advent of digital photography.

In the field of flame retarded products only the first three; fluorine, chlorine and bromine, are relevant.

Halogens have long been known to act as effective flame retardants. They are widely used to delay ignition, lower heat release, and lower flame spread.

However, when a material which contains halogen is forced to burn, the halogen is converted into halogen acid and this can have detrimental effects in some fire scenarios.

Question: What is meant by the term **“Halogen free”?**

Answer: Some standards define the term “Halogen free” For example:

EN 50264-1 “Railway applications – Railway rolling stock power and control cables having special fire performance. Part 1: General requirements”

This states that extruded insulation and sheath material shall have the following properties:

	Test method	Measurement	Requirements
1	EN 50267-2-2	pH and conductivity	pH ≥ 4,3 and conductivity ≤ 10 µS/mm
2	EN 50267-2-1	Chlorine and bromine content expressed as HCl	≤ 0,5%
3a	EN 50264-1 Annex B	Halogen: Fluorine	If negative stop test; no further test needed. Accept material If positive, do test according to 3b
3b	EN 60684-2	Fluorine content	≤ 0,1%

Draft IEC 60092-350, Ed. 3 "Electrical installations in ships – Part 350: General construction and test methods of power, control and instrumentation cables for shipboard and offshore applications." (IEC 18A/282/CDV), has a similar definition:

Test method	Unit	Requirements
Halogen gas emission test (IEC 60754-1) Bromine and Chlorine content (expressed as HCl), maximum	%	0,5
Fluorine content test (IEC 60684-2) Fluorine content, maximum	%	0,1
pH and conductivity test (IEC 60754-2) pH, minimum Conductivity, maximum	µS/mm	4,3 10

Question: What is meant by the term **"toxic"?**

Answer: The simplest answer is **"poisonous".** Scientists measure toxicity in terms of how much of a substance is needed to cause a defined effect, eg incapacitation or death.

All substances are toxic, but the amounts you would have to inhale, eat or drink to cause an adverse effect vary enormously. Even water is toxic if you drink too much (about 3 litres, if drunk in a short period of time can dilute the blood to a fatal extent).

The following figures give some idea of the range of different toxicities (on a scale where hydrogen cyanide =1):

N.B. The smaller the number, the more toxic the substance

Substance	Units required to kill you
Carbon dioxide	1308
Ethyl alcohol	113
Turpentine	81
Carbon monoxide	35
Hydrogen cyanide	1
Nicotine	0.091
Strychnine	0.055
Paraquat	0.018
Botulinus toxin *	0.00002

* This is one of the most toxic substances known and is a poison found in food which has been infected by the bacterium *Clostridium botulinum*.

Question: What is meant by the term **"zero halogen"?**

Answer: The term originated as a marketing term which meant that a product contained no deliberately added halogen (fluorine, chlorine or bromine). Today, a number of standards and specifications define what can be considered as "zero".

The term effectively excludes various polymers such as: fluoropolymers (eg PTFE, ETFE and Viton), chloropolymers (eg PVC, CPE and chloroprene rubbers), and it also excludes chlorine and bromine based flame retardant additives.

This means that if the product were involved in a fire it would not produce any halogen acid (hydrofluoric acid, hydrochloric acid or hydrobromic acid) in the fire effluent, which in some end-use environments (eg naval ships, submarines and underground trains) is recognized as being a desirable property.

However, it does not necessarily mean that the product would have other desirable fire hazard properties such as:

- Difficult to ignite
- Tendency to self-extinguish if the source of ignition is removed
- Low rate of flame spread
- Low heat release when it does burn
- Low level of smoke emission when it does burn
- Low level of toxic gas emission when it does burn

If there are good reasons why a "zero halogen" product is considered desirable, then the user should make sure that the product also has an appropriate balance of other desirable fire hazard properties.

It should be noted that petrol, napalm and TNT are all "zero halogen"!

For quantitative assessment the user will need to check to see if the product meets any defined standards with respect to fire hazard.

Question: What is meant by the term **"LFH"?**

Answer: LFH is an abbreviation for Limited or Low Fire Hazard. The term is a marketing term which is undefined unless further reference is made to define relevant standard tests.

When used in the area of Fire Hazard, it is used to indicate a combination of some, or all, of the following properties, e.g.

- Difficult to ignite
- Tendency to self-extinguish if the source of ignition is removed
- Low rate of flame spread
- Low heat release when it does burn
- Low level of smoke emission when it does burn
- Low level of toxic gas emission when it does burn
- Low level of corrosive gas emission when it does burn

For quantitative assessment the user will need to check to see if the product meets any defined standards with respect to fire hazard.

Question: What is meant by the term **"low smoke"?**

Answer: This term is a marketing term which is undefined unless further reference is made to define relevant standard tests.

When used in the area of fire hazard, it is used to indicate that if the product is burned, the amount of smoke which is produced will be relatively small.

For quantitative assessment the user will need to check to see if the product meets any defined standards with respect to smoke production.

Question: What is meant by the term **"low fume"?**

Answer: This term is a marketing term which is undefined unless further reference is made to define relevant standard tests.

When used in the area of fire hazard, it is used to indicate that if the product is burned, the fire effluent which is produced will have a relatively low toxicity.

For quantitative assessment the user will need to check to see if the product meets any defined standards with respect to toxic gas emission.

Question: What is meant by the term **"low smoke and fume"?**

Answer: The term is a marketing term which is undefined unless further reference is made to define relevant standard tests.

When used in the area of fire hazard, it is typically used to indicate a combination of the following properties:

- Low level of smoke emission when it burns
- Low level of toxic gas emission when it burns

For quantitative assessment the user will need to check to see if the product meets any defined standards with respect to fire hazard.

Polymer	Chemical name	Processing temperature	Flammability	Flash ignition temperature	Self ignition temperature	Operating temperature	
						Min	Max
PVC (rigid PVC) (unplasticised PVC)	poly(vinyl chloride)	150 - 200°C	Difficult to ignite Self-extinguishing Tends to char Will only burn if exposed to a continuous external heat source If it burns it produces HCl as well as C, CO, CO_2 and H_2O LOI ~ 47	391°C	454°C	-20°C	+80°C
PE	poly(ethylene)	150 - 210°C	Very easy to ignite Not self-extinguishing Produces molten flaming drips High heat release rate Burns to produce C, CO, CO_2 and H_2O LOI = 17.4	341°C	349°C	-60°C	+80°C
XLPE	cross-linked poly(ethylene)	Not processable after being cross-linked	Easy to ignite, but less than PE Not self-extinguishing Does not produce molten flaming drips High heat release rate Burns to produce C, CO, CO_2 and H_2O LOI > 18	> 350°C	> 350°C	-60°C	+135°C
PP	poly(propylene)	210 - 250°C	Very easy to ignite Not self-extinguishing Produces molten flaming drips High heat release rate Burns to produce C, CO, CO_2 and H_2O LOI = 18	320°C	350°C	0°C	+140°C
PES	polyethersulphone	300 - 360°C	Difficult to ignite Self-extinguishing Tends to char Burns to produce C, CO, CO_2, SO_2 and H_2O LOI = 39	~ 500°C	~ 500°C	-70°C	+210°C

Polymer	Chemical name	Processing temperature	Flammability	Flash ignition temperature	Self ignition temperature	Operating temperature	
						Min	Max
PC	polycarbonate	230 - 320°C	Not easy to ignite Self-extinguishing Tends to char Burns to produce C, CO, CO_2 and H_2O LOI = 27	467°C	598°C	-90°C	+130°C
Nylon 6,6	poly(hexamethylene adipamide)	270 - 280°C	Easy to ignite Not self-extinguishing Produces molten drips Burns to produce C, CO, CO_2, NH_3, HCN, NOx and H_2O LOI = 23	400°C	> 400°C	-40°C	+100°C
"Noryl" (Grade SE1GFN3)	blend of poly(phenylene oxide) and poly(styrene) with 30% glass fibre	300 - 320°C	Not easy to ignite Self-extinguishing Tends to char Burns to produce C, CO, CO_2 and H_2O LOI = 31	~ 500°C	~ 500°C	-50°C	+125°C
ABS	blend of cross-linked poly(butadiene) particles in a copolymer of acrylonitrile and styrene	205 - 260°C	Easy to ignite Not self-extinguishing Generally does not produce molten drips Burns to produce C, CO, CO_2, HCN, NOx, acrylonitrile and H_2O LOI = 18	~ 390°C	~ 500°C	-20°C	+80°C
GRP (Glass reinforced isophthalic polyester)	Polymerised and cross-linked combination of typically propylene glycol, maleic anhydride, isophthalic anhydride and styrene with glass fibre	20 - 100°C	Easy to ignite Can be self-extinguishing Tends to char Burns to produce C, CO, CO_2, and H_2O LOI ~ 19	370°C	485°C	-50°C	+105°C

Polymer	Chemical name	Processing temperature	Flammability	Flash ignition temperature	Self ignition temperature	Operating temperature	
						Min	Max
Wood (Red oak)	N/A	N/A	Easy to ignite Not self-extinguishing Tends to char Burns to produce mainly C, CO, CO_2, and H_2O LOI = 22.7	260°C	415°C	-45°C	+75°C
Wood (Douglas fir)	N/A	N/A	Easy to ignite Not self-extinguishing Tends to char Burns to produce mainly C, CO, CO_2, and H_2O LOI = 22	260°C	415°C	-45°C	+75°C

NOTE: Many of the above materials are available in the form of numerous grades and formulations. The above data should therefore be used only for guidance. For specific grades/formulations the supplier's data should be consulted.

Terminolgy

LOI	Limiting Oxygen Index
HCN	Hydrogen Cyanide
HCl	Hydrogen Chloride
C	Carbon
CO	Carbon Monoxide
CO_2	Carbon Dioxide
H_2O	Water
NOx	Oxides of Nitrogen
SO_2	Sulphur Dioxide
NH_3	Ammonia