PVC AND FIRE

Many studies have shown that the initiation and development of accidental fires are complex matters. A number of factors must be taken into account in assessing the contribution of any one material to a fire situation. These factors are dealt with in detail below. The various plastics materials used in the building and construction industries have differing reactions to fire. The high chlorine content of PVC polymer reduces its ignitability and also the heat it contributes to a fire, in comparison with other plastics. As the basic polymer is diluted with additives, the fire performance changes. High concentrations of organic materials will increase flammability; high concentrations of inorganic materials will reduce it.

PVC formulations, like other natural and synthetic materials, give rise to smoke and to toxic gases when they burn. Significant reductions in the emission of smoke and hydrogen chloride may be achieved by the use of special additives. Independent studies[1] have concluded that PVC fire gases are not significantly more toxic than those from other common building materials.

It has been recognised in a number of studies[2] that the substitution of traditional building materials by PVC brings no significant change to the hazards of accidental fires in buildings.

In a detailed assessment of the overall fire-performance of a material many factors must be taken into account. The following pages will explain this in detail.

IGNITABILITY

PVC is resistant to ignition. The temperature required to ignite rigid PVC is more than 150^{o}C higher than that required to ignite wood. The ignition resistance of common flexible PVC formulations is lower, but with specialised formulations it may be significantly increased.

In Table 9.1 ignition temperatures measured according to ASTM D1929 are listed for various natural and synthetic materials[3].

Table 9.1 Ignition Temperatures for Various Materials (ASTM 1929)

	Flash-Ignition (^{o}C)	**Self-Ignition (^{o}C)**
PTFE (Teflon)	560	580
Polyamide 6	420	450
ABS	390	480
Rigid PVC	**390**	**450**
Polystyrene	350	490
PMMA	300	430
Polyurethane-Rigid Foam	310	415
Polyethylene	340	350
Polypropylene	320	350
Pinewood	240	260
Paper	230	230
Cellulose Nitrate	130	130
Flexible PVC (Insulation)	330	385
Flexible PVC (FRLA*)	400	410

*FRLA = Fire resistant, low acid emission

FLAMMABILITY

Once a material has been ignited, the associated hazard will be related directly to its flammability. One of the most reliable quantitative small-scale flammability tests is the Limiting Oxygen Index test, which measures the limiting concentration of oxygen in an oxygen/nitrogen mixture necessary for sustained combustion. A material with a LOI value above 21 (air contains 21% oxygen) should not burn in air at room temperature, and a value above 25-27 means that the material will only burn under conditions of very high applied heat.

Rigid PVC has an oxygen index of 45-50, compared to 21-22 for wood and 17-18 for most thermoplastics. Oxygen index values above 27 can easily be attained with flexible PVC. The significance of this is that most rigid and flexible PVC will not burn alone without the application of heat from another source. Oxygen index values at room temperatures for various materials are listed in Table 9.2[4]. Some highly plasticised PVC formulations, such as those used in shower curtains, may sustain combustion alone.

Table 9.2 Oxygen Indices for Various Plastics

Polystyrene Foam	15
Polyurethane Foam	15
Polyaccial	15
Plexiglas)PMMA)	17
Polyethylene	17
Polypropylene	17
Polystyrene	17
ABS	18
SAN	19
Epoxy Resins	19
Polyester Resins	19
Polyamide	22
Polycarbonate	24
PPO	29
Polysulfone	30
Silicone	30
Phenolic Resin	35
Polyamide	36
Rigid PVC	**50**
Flexible PVC	21-36
PVDC (Saran)	60
PTFE (Teflon)	95
Wood	21-22

“Flammability Handbook of Plastics”. C J Hilado. 4th edn. Technomic. 1990

HEAT RELEASE

Burning materials release heat. The rate at which that heat is released largely determines the severity of the fire and the speed at which it spreads. Rigid PVC has a higher heat of combustion than wood or paper, but the rate at which it releases heat is significantly lower than for most organic materials[4]. This slow rate of heat release means that burning rigid PVC is unlikely to radiate enough heat to ignite nearby objects. Heats of combustion for various materials are listed in Table 9.3.

The addition of plasticiser to PVC to make it flexible may increase the rate at which it releases heat when burning. With a careful choice of additives this effect can be limited.

Table 9.3 Heats of Combustion for Various Materials (KJ/Kg)

Polyethylene	46500
Polypropylene	46000
Gasoline	44000
Polystyrene	42000
ABS	36000
Polyamide	32000
Polycarbonate	31000
PMMA	26000
Polyurethane	25000
Rigid PVC	**20000**
Paper	18000
Wood	17000
PTFE (Teflon)	4500

"Flammability Handbook of Plastics". C J Hilado. 4th edn. Technomic. 1990

SPREAD OF FLAME

Many PVC formulations exhibit limited flame-spread in standard laboratory tests. For example they may achieve the 94 V-O rating in the Underwriters Laboratory vertical flammability test. In national building tests many PVC formulations qualify for the best possible classifications for combustible building materials and examples are shown in Table 9.4

Table 9.4 Typical National Building Test Performance

Country	Test Method	Classification
UK	BS 476 Part 7	Class 1 (a)
UK	BS 476 Part 6	Class 0 (b)
France	NF P92 – 501	M1
Germany	DIN 4102 Part 1	B1
USA	ASTM E84	Class 1

a) Class 1 can usually only be achieved with PVC when it is reinforced or when it is fixed to a non-combustible backing such as concrete. According to BS 476, Part 7 materials which become detached from the substrate are unclassifiable.

b) Class O of the UK Building Regulations, which is achieved by appropriate performance in both Part 6 and 7 of BS 476.

In contrast to most other thermoplastics, PVC formulations do not drip when burning, but instead develop a carbonaceous char which inhibits the spread of flame. The emission of hydrogen chloride as the PVC decomposes also inhibits combustion.

SMOKE EMISSION

The smoke produced by burning materials is important because it may obscure exit routes from fire situations and it may induce disorientation in fire victims, so hindering their escape.

Smoke is a result of the incomplete combustion of a burning material, and it is defined as a dispersion of solid or liquid particles in the combustion gases. The extent and type of smoke formation depends on factors such as fire intensity and oxygen supply, as well as on the nature of the material burning. Under non-flaming conditions, PVC formulations give similar smoke densities to those produced by wood. Under flaming conditions PVC produces greater total quantities of smoke. However, the low rate of heat release when PVC is burning means that the rate of smoke emission per unit of time is lower than for most organic materials, providing more time for safe escape from a fire.

The smoke emission characteristics of materials may be compared in the US National Bureau of Standards smoke chamber under the conditions specified in standards such as BS6401 and values for a range of building materials are given in Table 9.5.

Table 9.5 Smoke Emission Measurements in the US-NBS Smoke Chamber (BS6401 conditions)

Material	Thickness (mm)	Maximum Specific Optical Density (DM) Non Flaming	Flaming
PLASTICS			
UPVC	3	400	580
Polyethylene	3	590	83
FR Polyethylene	3	790	780
Polypropylene	3	550	162
FR Polypropylene	3	820	600
Polystyrene	3	476	960
PMMA	3	63	117
Plasticised PVC	0.75	430	650
OTHER MATERIALS			
Hardboard	3	580	74
Pine	6	551	132
Plywood	6	432	64
Chipboard	19	620	405
Oak	19	581	243
Plasterboard	12	77	83
Wool Carpet	6	388	217
Natural Rubber (Black)	2	721	762

Edgerley P G and Pettet K "The Effect of Pyrolysis and Combustion Temperatures on Smoke Density Fire and Materials" Vol 2 No 1 pp 11-17 1978.

TOXIC GAS EMISSIONS

All organic materials, natural or synthetic, give rise to toxic gases upon combustion. The major gaseous products of the combustion of PVC are carbon monoxide, carbon dioxide, hydrogen chloride and water. Chlorine gas is never produced when PVC burns, and while the possibility of producing phosgene from burning PVC has been suggested, following reports of minimal quantities produced in laboratory experiments, it has never been detected in large scale fire tests and it is not considered a significant product of PVC combustion.

Dioxins and furans can be formed when PVC materials are incinerated. However, it appears difficult to come to definite conclusions from laboratory tests as to the quantity of these materials produced from burning PVC in real fire situations. Investigations of fires where considerable quantities of PVC were burned have shown that much smaller quantities were produced than might be expected from laboratory tests. For example large quantities of PVC and PVC flooring were consumed in a warehouse fire in Holmsund in Sweden. Weather conditions at the time of the fire were ideal for measuring the quantities of dioxins formed. The analyses performed showed that the amount of dioxins and furans produced was one thousandth of those measured when a comparable weight of PVC was burnt in a Swedish refuse incineration plant in the 1980's. Moreover, several tests have shown that timber can be a source of dioxins under fire conditions, and so it would be difficult to establish only one source of these substances in building fires. A UK review has listed all the known sources of dioxins in the UK atmosphere, including accidental fires. The relative importance of the various sources is shown in Figure 9.1 and 9.2 in UK and Berlin respectively. Accidental fires represent a very small proportion of the total burden.

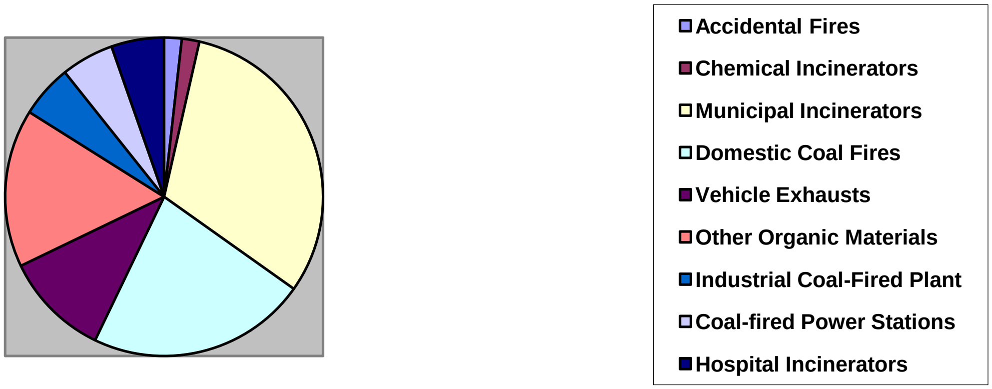

Figure 9.1 *– Estimated relative contribution to total TCDD released into the atmosphere from combustion sources.*

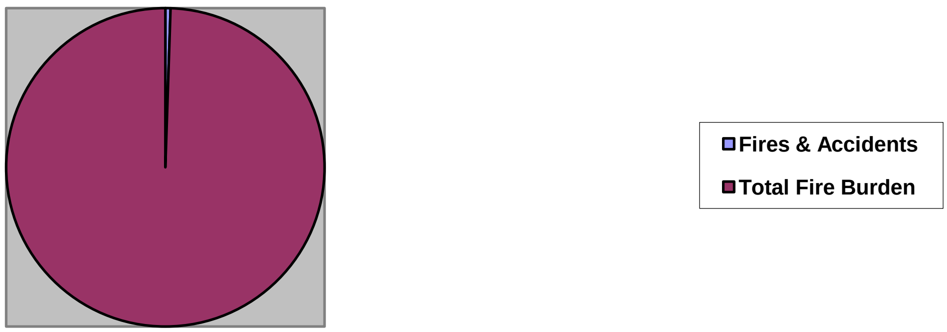

Figure 9.2 *– Total Dioxin Formation = 0.01%*
Source: Obermeier T "Impact of Waste Incineration on Dioxin Emission" Warner Bulletin, Feb. 1992

The presence of hydrogen chloride in fire gases will be very obvious to people nearby from the earliest stages of the fire, because it will cause irritation of the mucous membranes at concentrations much lower than those likely to cause a threat to health. Thus it will provide a warning of the fire not available from carbon monoxide alone. At higher concentrations, hydrogen chloride could cause damage to the lungs, but it is not more toxic to animal life than carbon monoxide, which is a major constituent of all fire gases.

Hydrogen chloride is considerably less toxic than gases such as acrolein and hydrogen cyanide, which can be formed by the combustion of other common materials such as wood, leather or wool. The United Nations Organisation classifies materials on the basis of their toxicity into three categories or increasing severity: HARMFUL, TOXIC AND HIGHLY TOXIC. Hydrogen chloride is placed in the HARMFUL category along with carbon monoxide. Similar conclusions are drawn by the US Foundation for Applied Combustion Toxicology in their 1986 Code of Practice.

Looking at the combustion products of PVC as a whole, research suggests that they are not significantly more toxic than those from other building materials. The toxic potential of various combustion gases is compared with everyday materials in terms of their LD50 values in Table 9.6.

Table 9.6 The Toxic Potential of Combustion Gases & Other Common Substances as Measured by Their LD50 Values – Lethal Dose (LD50)

Ethanol	16000
Carbon dioxide	1300
Methanol	425
Chloroform	300
Aspirin	250
Hydrogen Chloride	27
Carbon Monoxide	22
Nicotine	1
Hydrogen Cyanide	0.75
Cocaine	0.50
Toluene di-iso-cyanate	0.50
Acrolein	0.40
Strychnine	0.25
Phosgene	0.17
Dioxin	0.025
Botulinus toxin	0.0002

Source: “How Hazardous is PVC” M M Hirschler “Fire Prevention” Nov 1987

CORROSION HAZARD

Burning PVC gives off a mixture of gases, including hydrogen chloride. Most organic materials are capable of releasing corrosive combustion products. Wood, chipboard and cotton can all initiate corrosion of metal surfaces when they burn.

Burning PVC has resulted in corrosion damage to electrical equipment in the vicinity. This has led to suggestions that PVC should not be used in construction applications. Against this should be set other factors. PVC components can be formulated to combine a good technical performance and high resistance to ignition and flame-spread. Formulations can also be designed to reduce the quantity of hydrogen chloride emitted. There have been suggestions that hydrogen chloride from burning PVC may damage steel reinforcement in concrete, or significantly weaken unprotected steel structures. The UK Fire Research Station has shown that reinforcement is not normally affected. It has also been confirmed that unprotected steel structures are distorted and weakened by heat rather than by hydrogen chloride.

For applications with very high fire risks, for example oil rigs and nuclear installations, more expensive, high performance insulating materials are preferred to PVC. The cost of post-fire clean-up operations must be included in assessing the total cost of fire damage. Just as soot can be removed from affected equipment, so chloride corroded parts can be reconditioned. This is well recognised by fire salvage consultants and by insurance companies.

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