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Assessment of Toxic Potency of Smoke from Burning Materials

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Abstract: *The building material performance testing has its own importance in fire safety. Small scale tests can be used for identification of toxic gases emitted during the combustion of commonly used materials in the building. Fire hazard of selected samples of building materials, structural as well as those used in the interiors were assessed. Smoke toxicity were studied by testing the samples of POP, plastics, laminates, foam, aluminium, ceramic tiles, window blinds, paper, plywood, PVC and rubber to identify the various gases emitted during their combustion. The toxicity of the gas emitted from the material classifies the material fit or unfit for use as far as fire hazard is concerned. Identification of such materials and restricting their use will reduce the fire hazard to some extent. Plastic and PVC was found to be most toxic of all. The main disadvantage is that they are combustible. Certain treatments /can increase ignition temperatures and inhibit flame spread, but they cannot be made non-combustible.*

1. INTRODUCTION

The main direct cause of deaths in fires is however, as it has always been the toxicity of combustion products. In a fire incidence materials get heated up to their ignition temperatures and start burning and in the process emit smoke and various gases. The dense smoke reduces vision and presence of irritant gases causes a person to lose sense of direction during escape. The prediction of the hazards to life of people from exposure to fire effluents, including heat, smoke and toxic gases, is an important part of fire hazard assessment and fire safety engineering.

In UK, study of the Pathological studies of almost 300 autopsies of fire victims carried out between 1976 and 1982 shows damage to the respiratory system (congestion, oedema, haemorrhaging). Of all the fire victims 90% of the victims had inhaled fumes and deposits of soot were found in the airways. Just over half of the victims had the carboxyhaemoglobin-in-blood level of over 50%, which is regarded as fatal in itself. Carbon mono oxide was present in 37% cases and HCN formed in many of the fires from materials containing nitrogen in combination with carbon, is another toxic gas which had contributed to the death of 20% of cases[1].

Therefore, the material used in construction and interiors of a building plays a vital role in fire safety and shall be selected taking all these factors into consideration. The recent standard ISO 13344: 2004 is the first normative international standard on smoke toxicity[2].

2. TOXIC GASES AND VAPOURS

One of the important aspects of fire hazard is the toxic fire hazard. The toxicity of smoke is a direct measure of the concentration of toxic products contained in it [1].

Most toxic products in fire environment belong to one of the two categories:
Narcotics: such as CO, HCN, Benzene, Acetone etc., high concentrations renders an exposed person unconscious. Lower concentration acts on nervous & cardiovascular system & reduce mental & motor functions to the point where escape becomes impossible.

Irritants: Ammonia, Hydrochloric acid (HCl), phosgene or acrolein prevents escape by affecting eyes & upper airways, can also damage the lungs and cause subsequent death of victims who have survived immediate exposure.

All such gases cause excessive flow of tears from tear ducts which in turn causes blurring of vision. The respiratory tract is also affected causing coughing & choking. One of the main purposes of building material control may be to keep people alert in the building during egress. But to say what fire property control of material is necessary, we have to analyze the requirements carefully. The current expression of the requirement is based on the classification using test. The assessment of 'reaction to fire' characteristics of materials is carried out using standard fire test facilities. Tests were carried out at Anacon laboratories, Nagpur; with an aim of assessing the toxic potency of smoke generated from combustion of various materials used in building. The toxicity of smoke is a direct measure of the concentration of toxic products contained in it.

The objective being:

- Identification of materials which represents unusually toxic fire hazard by emitting toxic gases.
- Classifying materials by categories of toxic potency.

The table shows the types of gases or vapours produced by burning some of the common building materials. This is only the approximate estimate as the actual amount of gas produced anyway will finally also depend upon the circumstances prevailing in the room like ventilation, room temperature etc.

3. TEST RESULTS

Table 1: Table showing the presence of various gases after combustion of POP, Plastics, Rigid foam & Aluminium

S.No	Test Parameter	Measurement Unit	Sample Particulars			
			POP	Plastic	Rigid Foam	Al.
1.	O2	%	20.3	21.1	20	20.2
2.	NOx	ppm	10	35	83	16
3.	SOX	ppm	328	340	--	117
4.	CO	ppm	80	754	781	105
5.	HCN	ppm	--	0.003	--	--
6.	HCl	ppm	--	0.39	--	--
7.	CO2	%	27.91	27.63	27.50	27.63
8.	Isocynate	ppm	--	--	0.05	--

Table 2: Table showing the presence of various gases after combustion of Ceramic tiles, Blinds, Laminates & Paper.

S. No	Test Parameter	Measurement Unit	Sample Particulars			
			Ceramic Tiles	Blinds	Laminates	Paper
1.	O2	%	21.8	22.6	20.10	7.0
2.	NOx	ppm	8	52	242	71
3.	SOX	ppm	28	186	---	257
4.	CO	ppm	70	380	1000	1000
5.	HCN	ppm	--	0.01	--	0.001
6.	HCl	ppm	--	0.2	--	0.03
7.	CO2	%	28.18	29.32	27.63	9.62
8.	Isocynate	ppm			--	--

Table 3: Table showing the presence of various gases after combustion of Loose foam, Plywood, PVC & Rubber

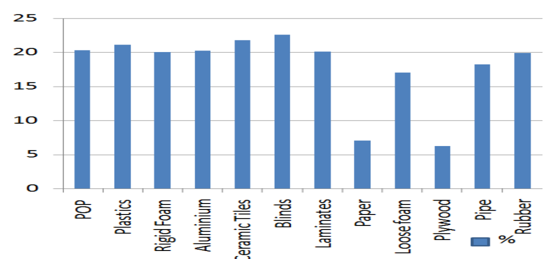
S. No	Test Parameter	Measurement Unit	Sample Particulars			
			Loose foam	Plywood	PVC	Rubber
1.	O2	%	17	6.2	18.2	19.9
2.	NOx	ppm	79	89	10	51
3.	SOX	ppm	1000	---	152	160
4.	CO	ppm	563	1000	658	858
5.	HCN	ppm	--	0.01	0.02	--
6.	HCl	ppm	--	--	ND	--
7.	CO2	%	23.37	8.52	25.02	27.5
8.	Isocynate	ppm	0.04	--	--	--

4. ANALYSIS OF TESTS

The graph generated from the readings of the table shows the presence of a particular gas in various materials being combusted. A brief information about the gas and observations are recorded.

Oxygen (O2)

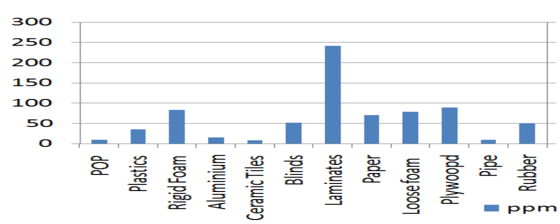
Some fuels expel oxygen on burning; in such cases removal of atmospheric oxygen will not be sufficient to extinguish the fire. Incomplete combustion will occur when there is not enough oxygen to allow the fuel to react completely to produce carbon dioxide and water.



Graph 1: Graph showing amount O_2 evolved on combustion of different materials.

NOx

NO_x readily reacts with common organic chemicals, and even ozone, to form a wide variety of toxic products: nitroarenes, nitrosamines and also the nitrate radical some of which may cause biological mutations.



Graph 2: Graph showing amount NO_x evolved on combustion of different materials.

When NO_x comes into contact with salt mist, it forms Nitryl chloride.

Observation

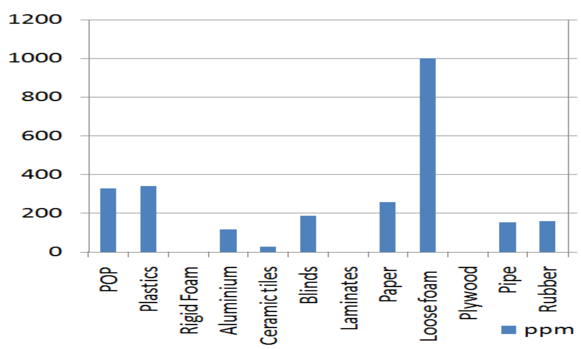
- Maximum presence is found in laminates, then in Foam and Plywood.

Effect on human beings

Nitrogen Oxides (NOx) are a family of gases that can cause a number of serious health effects. One form of NOx, nitrogen dioxide, is unhealthy to breathe, especially for children, the elderly, asthmatics and people with chronic obstructive pulmonary disease. NOx also reacts with ammonia, and other compounds to form nitric acid and related particles. These tiny particles cause effects on breathing and the respiratory system, damage to lung tissue, and even premature death.

SOx

SOx refers to all Sulphur oxides, the two major ones being Sulphur dioxide (SO2) and Sulphur trioxide (SO_3). Sulphur dioxide in concentration of one percent for five minutes can be lethal or produce serious injury. It itself is not as harmful as is the mixture of Sulphur dioxide with Hydrogen cyanide. Such mixtures are normally evolved due to burning of rubber of all types. It is 2.25 times heavier than air due to which it tries to remain at floor level. Thus, it remains at clear air space due to which escape from fire by crawling becomes very difficult.



Graph 3: Graph showing amount SO_x evolved on combustion of different materials.

Observation:

- Maximum evolution is in foam.
- Mixture of Sulphur dioxide with Hydrogen cyanide are evolved due to burning of rubber of all types.
- It is 2.25 times heavier than air.

Effects on human beings:

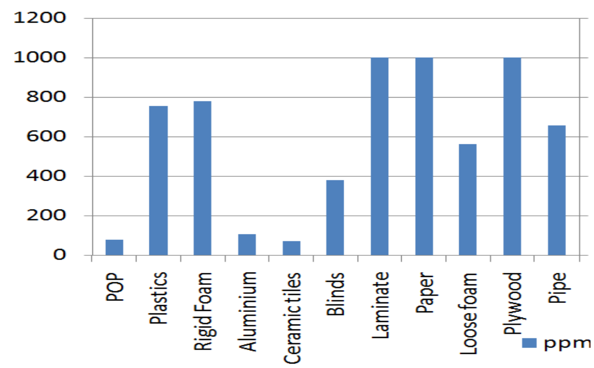
Sulphur dioxide irritates the throat and lungs and, if there are fine dust particles in the air, can damage a person's respiratory system. Sulphur oxides combine with other substances in the air to produce a haze that reduces visibility. SO_2 in concentration of 1% by volume in 5 minutes can be lethal or produce serious injury. Small concentration of this mixture in air of even 0.05% by volume may be lethal.

Carbon mono oxide (CO)

Carbon monoxide is the toxic gas with greatest individual fire hazard. It is present in all fires, because it is combustion product of any organic material. It is toxic to humans when encountered in concentrations above about 35 ppm, and is most dangerous component of all fire by products, as even high as its 10% concentration is dangerous for short period exposure. In limited atmosphere there is every chance that it gets highly dangerous. More or less this gas is always formed in fire of any type but specially formed in cases when too little oxygen is left in the local atmosphere.

Observation

- CO is present in all fires, that too in very high quantity.
- It is nearly present in greater concentration than other gases
- In burning Plywood the main toxic hazard is Carbon Mono-oxide.
- Maximum presence is found in laminates, Paper and Plywood.



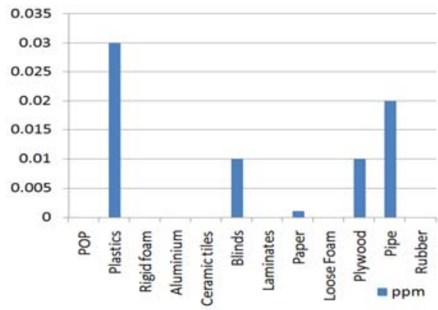
Graph 4: Graph showing amount CO evolved on combustion of different materials.

Effects on human beings:

Its presence in body causes formation of COHb in blood. Presence of concentrations as low as 667 ppm may cause up to 50% of the body's haemoglobin to convert to carboxyhaemoglobin[2]. Any value above 20% can lead to death, it alone accounts for 60% of all fire deaths, while over 91% of fire victims have levels above 20%. It has been stated that exposure to atmosphere containing 1% of CO will result in loss of consciousness in less than 5 minutes & thus cause death in very short time. A concentration of 0.2% can be lethal in 40 minutes.

Hydrogen Cyanide (HCN)

HCN, is another toxic gas which has contributed to death of 20% of the cases. A very small concentration of gas is lethal (0.01% by vol). Sources of cyanide toxicity include the increased use of synthetic polymers in building materials and furnishings. Prompt recognition of and therapy for cyanide intoxication may reduce the morbidity and number of delayed deaths in fire victims.



Graph 5: Graph showing amount HCN on combustion of different materials.

Observations:

- Mainly produced out of combustion of plastics & plastics containing nitrogen in combination of carbon.
- It may be produced out of combustion of wool, silk, nylon, leather, acrylic fibres, polyurethane foams, rayon cellulosic materials etc.

Effects on human beings:

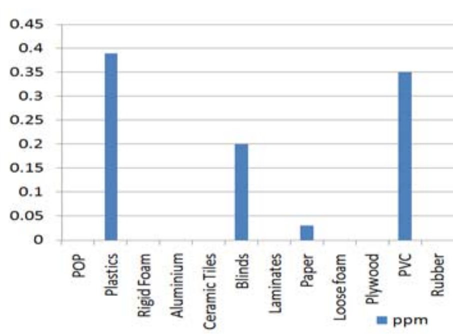
A Hydrogen cyanide concentration of 300 mg/m^3 in air will kill a human within 10–60 minutes. Hydrogen cyanide gas, the most toxic product of combustion, seldom is recognized as a significant hazard in smoke inhalation. A hydrogen cyanide concentration of 3500 ppm (about 3200 mg/m^3) will kill a human in about 1 minute. The toxicity is caused by the cyanide ion, which halts cellular respiration by acting as a non-competitive inhibitor for an enzyme in mitochondria called cytochrome oxidase.

Hydrogen chloride (HCl)

Hydrogen chloride (HCl) gas is an incapacitating irritant. It is evolved from burning PVC, and other chlorine containing plastics[3].

Observations

- It is evolved from burning PVC, and other chlorine containing plastics.



Graph 6: Graph showing amount HCl on combustion of different materials.

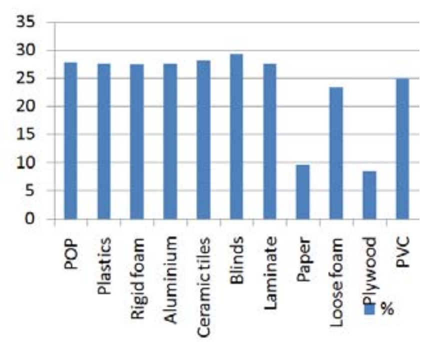
- Breakdown of PVC occurs between 300 -500^0 and total chlorine content is transformed into hydrogen chloride. Rate of production of HCl depends on the ventilation conditions of the room. If the ventilation is small, the gas will be produced very slowly and vice versa.

Effects on human beings:

HCl is an acid gas which causes severe irritant effects at low concentrations (around 100 ppm) but only results in death at very high concentrations (in mice 2600 ppm, rats 4700 ppm for 30 minute exposures)[4]. Humans can tolerate exposure to 10 ppm HCl, while at 70 and 100 ppm humans have to leave the room because of intense irritation, coughing and chest pains, indicating that 100 ppm is intolerably irritating to humans, by inhibiting the conversion of CO to CO_2. The concentration causing incapacitation, and thus preventing escape, is much lower than that causing death directly; it is considered intolerable to humans at 100 ppm although a value of 1000 ppm given for incapacitation in the ISO 13571 standard.

Carbon di-oxide

Carbon dioxide is non-toxic, non-poisonous and uninflammable gas. This is major component of combustion products and is found naturally as 0.04% (by volume). Any fire may get self extinguished automatically when the CO2 content of the local atmosphere by volume exceeds 14% by volume. It is produced by combustion of wood, carbohydrates and major carbon and hydrocarbon-rich fossil fuels such as coal, petroleum and natural gas.



Graph 7: Graph showing amount CO_2 evolved on combustion of different materials.

Observation:

- Almost equal percentage of CO2 gas is emitted from all the material under combustion.
- It is non-toxic, non-poisonous & inflammable gas but can cause death by suffocation if its concentration in air is very high.

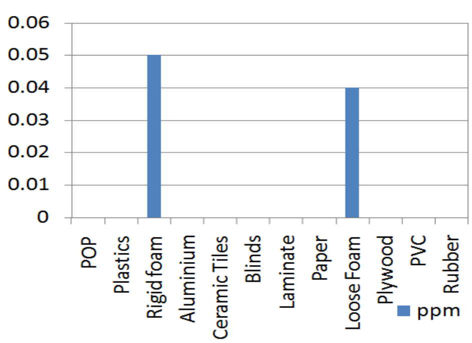
Effect on human beings:

CO_2 is an asphyxiant gas and not classified as toxic or harmful in accordance with Globally Harmonized System of

Classification and labeling of Chemicals standards of United Nations Economic Commission for Europe by using the OECD Guidelines for the Testing of Chemicals. In concentrations up to 1% (10,000 ppm), it will make some people feel drowsy; 7% to 10% may cause suffocation even in the presence of sufficient oxygen, manifesting as dizziness, headache, visual and hearing dysfunction and unconsciousness within a few minutes to a hour[5]. CO_2 is least hazardous to human health and is less likely to be produced during the fire but can cause death by suffocation if its concentration in air is very high. Its presence in more than 5% proportion may prove lethal in approximately 40 minutes. This is because the rate of breathing increases, thus aggravating a situation where the O_2 supply may already be low.

Isocynate:

Isocyanates are compounds containing one or more N=C=O groups which can combine with other compounds containing alcohol groups. A generic term used to cover all macro-molecular products made by this process is polyurethane. The largest volume use of isocyanates is in the production of polyurethane foams. Methyl isocyanate (MIC) is an organic compound with the molecular formula CH_3NCO. Synonyms are isocyanatomethane, methyl carbylamine, and MIC. Methyl isocyanate is an intermediate chemical in the production of carbamate pesticides (such as carbaryl,carbofuran, methomyl, and aldicarb). It has also been used in the production of rubbers and adhesives.



Graph 7: Graph showing amount of Isocynate evolved on combustion of different materials.

Observation

- Of all the materials it is seen released from only foam, that too in very little quantity.

Effects on human beings:

Isocyanates are potentially dangerous irritants to the eyes and respiratory tract, despite their relatively low acute toxicities. As a highly toxic and irritating material, it is extremely hazardous to human health. Diisocynates are severe bronchial irritants and asthamagens associated with chronic exposures that can be fatal at high exposure to sensitive individuals[4] . It was the principal toxicant involved in the Bhopal disaster, which killed nearly 8,000 people initially and approximately 20,000 to 30,000 people in total. People exposed to isocyanate gas are degraded rapidly in the air by reacting with substances. Asthmatic people are more prone to sensitisation and other adverse reactions. People with a history of asthma should not be exposed to Isocyanates.

5. TO SUM UP

CO_2 is least hazardous to human health and Bromine is highest, but is least likely to be produced during the fire. Gases like Hydrogen chloride, phosgene etc. create very irritant effect on human beings which compels the ocupants of the building to leave the building momentarily and thus causes panic. CO is present in all fires, and is also the cause of deaths in fires. The largest quantities are produced in rooms whose contents are cellulosic and represent a high fire load (6-18 % of the wall surface) and where there is little ventilation i.e normal domestic conditions.

The common combustible materials and type of toxic gases or vapours produced by burning them are shown in the table. The main hazardous gases are Carbon monoxide, Hydrogen cyanide and Sulphur dioxide. Studies also point out that potentially most dangerous gas in fires acrolien, because the ratio of its concentration, as measured in the atmosphere of real fires, to its lethal exposure dose is higher than for many other common fire gases.

Table 4: Toxic compounds which may be produced by combustion of various materials

Toxic gas or vapour	Source material
Carbon dioxide, carbon monoxide	All combustible material containing carbon
Nirtrogen oxide	Celluloid, Polyurethanes
Hydrogen cyanide	Wool, silk, leather, plastics, containing nitrogen
Acrolein	Wood, paper, cotton
Sulphur dioxide	Rubber, thiokals
Halogenated acids (HCl, Hbr, HFl,Phosgene)	Polyvinyl chloride, fire retardant plastics, flourinated plastics, materials with halogenated flame retardants
Ammonia	Melamine, nylon, urea formaldehyde resins
Aldehydes	Phenol formaldehydes, wood, nylon, polyster, resins
Benzene	Polystrene, PVC, polysters
Azo-bis-succino-nitrite	Foamed plastics
Antimony compounds	Some fire retardant plastics
Isocynates	Polyurethane foam

6. SOME FACTS OF BUILDING MATERIALS TO BE CONSIDERED

- Smoke from most natural materials (wood, wool, paper) and from most synthetic materials (plastics, foams, rubbers) is virtually identical in toxic potency.
- Most important toxicant in fire is Carbon monoxide (CO), which results from combustion of all organic

materials. All the petrochemical based materials in use today are source of toxic gases. These include chlorinated plastics including polyvinyl chloride[6]. The chlorine content has the potential to produce dioxins when burned. Dioxins include some of the most potent carcinogens known to humankind[6]. Dioxins are a family of compounds widely recognized as persistant bioaccumulative toxicants which have a tendency of altering the immune and endocrine systems[7]. In building PVC is used in resilient flooring, ceiling tiles coatings, carpet backings, pipes and conduits, siding, window treatments, furniture, wall and corner gaurds, wiring and cable sheathing, wall covering and upholstery fabric.

- Many chemicals are added to building materials to provide them with qualities often sought after in the building industry. Many of these chemicals fall under the category of problematic compounds[7].
  - Volatile Organic Compounds (VOCs)
  - Semi volatile Compounds (SVOCs)
  - Heavy Metals

These chemicals are human carcinogens and raise health and environmental concerns.

VOC type chemicals are used in binders and other resins for products such as composite wood and insulation, in paints, coatings and adhesives, treatments to provide water resistance and enhance stain resistance. Building material finishes and furniture that contain VOCs include carpet, resilient flooring, fabrics, furniture, wall covering, ceiling tiles, composite wood products, insulation paints and coatings, adhesives stains, sealants and varnishes. Semi volatile organic compounds (SVOCs) are used in building materials to provide flexibility (phthalates) water resistance and stain repellence (perflourochemicals) as well as to inhibit ignition or flame spread (halogenated flame retardants). PFCs are found in carpets, upholstery, fabric and furniture and other places where water repellent and stain resistance is preferred.

- Some of the heavy metals in their element or compound form are of concern to humans for their toxicity include arsenic, antimony, cadmium, chromium, copper, cobalt, lead, mercury zinc etc. Heavy metals are used as stabilizers in vinyl plastic materials, most notably wire insulation, and other PVC products and be found in variety of other uses in roofing, solder, radiation, shielding, and in dyes for paints and textiles. They release toxins and can have serious effect on human and ecosystem health.
- Furnishings are generally the first material to ignite, & when burning, produce large amounts of heat, toxic smoke and gases. This is relatively a quick process, without permitting people time to be alerted. Furnishings play a key role in the initial development of the fire. Furnishings are generally the first material to ignite, and when burning, produce large amounts of heat, toxic smoke and gases. This is relatively a quick process, without permitting people time to be alerted.

7. CONCLUSION

One of the possibilities of ensuring fire safety is to use only those materials which do not burn at all. A more practical approach can be to select and use materials which do not contribute significantly to growth of fire and do not emit toxic gases on combustion. Materials used needs to be evaluated for their likely fire behavior and only those found suitable to be recommended for use. The market must respond to concerns about harmful building materials and offer alternatives to them. For eg. Mainstream business institutions like Wal- Mart has moved to replace PVC with alternative materials. The Healthy Building Network and Health care without Harm have put together a list of PVC free interior flooring and finishes products which can be found in www.healthybuilding.net.

The fire hazard of a material along with the toxic gases emitted is determined by combination of variety of fire properties, including ignitability of the material, the flammability, the amount of heat released when it burns, the rate of heat release, the smoke production tendency and the intrinsic toxic potency of the smoke. Certification standards are to be set up and list of materials that have met the certification standards for toxic gas emission to be produced for reference to reduce the fire hazard.

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