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Flammability of Vinyl Foam Backing

By M.M O'Hara

Abstract

Recent studies on the flammability of commercial carpeting are discussed within the framework of smoke generation, toxicity of combustion products and flame retardancy. A number of different formulations including PVC have been evaluated.

Although there is presently considerable concern about smoke and toxic gas generation during a fire, the major emphasis must be toward new concepts in flame retardation. In addition new methods of measuring and evaluating toxic gases are needed.

The tremendous need for new flame retardant materials which also afford smoke and toxic gas retardation presents a challenge to the vinyl industry that can not be ignored. Stricter federal legislation in the area of flammability, toxic gas and smoke generation makes this challenge all the more urgent.

To meet this challenge, a program dealing with the various aspects of flame retardation is now being formulated.

The following exerpts were extracted from an article published in the Plain Dealer (2/9/70) with regards to the Marietta Nursing Home fire.

> "The carpeting and backing throughout the facility were burned away; it appeared that heavy, dense acrid smoke was generated from the smoldering or burning of this carpeting, creating the deadly atmosphere."

> "The fire spread very rapidly, and it is the feeling of the investigators that the carpeting and rubber backing... contributed to the spread of the fire and was the cause of the heavy, dense, black smoke."

This fire has initiated a series of Senate hearings into the adequacy of the Flammable Fabrics Act of 1967. The carpeting in the Marietta Home (reportedly of Nylon/SBR composition) met the minimum requirements under the FFA. The fact that all carpeting material will undergo increased scrutiny with respect to flammability, toxic comubstion products and smoke generation has prompted a number of questions about vinyl carpet backing. How does it compare with SBR and other materials with respect to the above considerations?

Is vinyl carpeting potentially more dangerous then other materials since it releases a stoichiometric amount of HCl during combustion? Is there toxicological synergism with HCl and carbon monoxide (as with HCN and CO)? How does vinyl carpet backing compare with other materials with respect to smoke generation? What effect does heat generation, during a fire, have on toxic gas and smoke generation?

The objective of this paper is to answer some of these questions within the framework of recent government sponsored studies and to show the need for further studies in the area of toxicity, flame retardancy and smoke generation. This need is due not only to the fact that there will be future federal legislation in this area but also due to the fact that much of the work in the past (especially with respect to toxicity) is totally inadequate for today's needs.

Primary Causes of Death in a Fire

At a recent symposium on the flammability of synthetic materials,[1] Prof. I. Einhorn, symposium chairman, related that in his discussions with people in the fire prevention business, the causes of death in a fire (in order of decreasing importance) are:

1. asphixiation due to oxygen depletion
2. effects of superheated air
3. impairment of visibility by smoke
4. toxic effect of gases
5. heat from the fire and
6. varying degrees of 1-5

Thus in most fires asphixiation due to oxygen depletion (or dense smoke) is the major cause of death.

This is not to suggest that smoke generation and toxic gas evolution play a minor role in this respect. Indeed, as more material in the home is rendered flame retardant thereby reducing the possibility of torch fires, the combination of smoke and toxic gases becomes of greater importance with respect to fire deaths. James Gaskill, in a paper on the analysis of smoke developed during a fire (work carried out at Lawrence Radiation Laboratory) has stated[3] that "except for clothing fires, more than half the deaths due to fire are caused by smoke rather than by heat or burning." (Gaskell's definition of smoke includes solid particles, toxic gases and suspended liquids)

Although considerable attention is being given to smoke and toxic gas generation these days, primary concern and basic research must deal with new concepts in flame retardation. Although the deaths at Marietta may have been due to a combination of smoke and toxic gases, the ultimate cause of death was due to the flammability of the carpeting.

Toxicity of Combustion and Degradation Products

Attempting to rate most materials with respect to the toxicity of their combustion products is more or less academic. When any material, ranging from wood to Teflon is burned, the combustion gases are toxic. In a recent study[2] at the National Bureau of Standards, 141 materials designed for aircraft interiors were evaluated with regard to smoke generation and toxicity of combustion products. The concentration of CO, HCl and other gases were measured in the smoke chamber and the reported values are the maximum concentrations observed. Table I contains a summary of these values for a number of materials used in carpeting formulations. Gross[2] has reported the values in ppm of air. However, this author feels that these values are misleading due to the fact that different weight samples (same dimensions) were used in the smoke test. Gross has given the weight of the samples consumed so the values in Table I are reported in terms of ppm per g

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sample burned. In this way, all materials can be judged on the same basis i.e., weight...

TABLE I : Concentration [ppm]/g material of HCl, CO and HCN From Flaming (F) and smoldering (S) Rug Materials

Composition	CO F	CO S	HCl F	HCl S	HCN F	HCN S
	[ppm]/g sample burned					
Pile: Modacrylic Backing: Polyester fiber Pad: Polyester urethane	41.0	10.2	7.4	2.5	1.6	2.5
Pile: poly (propylene-butylene) Center: Celluloeic Backing: Polyethylene	20.0	114.0	0	0	<1	<1
Wool	20.2	9.6	0	0	1.6	2.1
Pile: Wool Back: Polyester Pad: Urethane foam	21.1	19.8	0	0	<1	4.0
Modacrylic/Acrylic	24.3	20.7	2.6	<1	<1	4.3
Polyester urethane foam (carpet underlay)	88.5	26.5	0	0	<1	0
Modacrylic/Acrylic	31.4	13.2	2.5	0	2.1	4.4
" "	36.1	20.5	0	0	2.0	13.3
Plasticized PVC/PVA (Flooring, Rigid)	43.6	13.7	49.2	27.3	<1	<1
Polyamide	81.5	93.0	0	0	5.6	4.7

Although these data appear to show the relative toxicity of the various materials listed, this writer feels that the study is of limited use. For example, since one of the primary aspects of most fires is oxygen depletion, the effect of this parameter on the concentration of carbon monoxide is of primary importance. Yet all of the analyses listed in Table I were carried out on systems containing a normal level of oxygen. It cannot be assumed that the same relative order of CO concentrations appearing in Table I will also occur under conditions of limited oxygen concentration. For example, the differences in the levels of CO generated under flaming and smoldering conditions vary considerably.

The PVC plastisol is an interesting example of the limited use of the data. The high level of hydrogen chloride in the combustion gases indicates that this particular formulation for carpet backing is extremely dangerous. (This is based on the fact that the Maximum Allowable Concentration of CO is 50 ppm, that for HCl is 5 ppm). Two additional pieces of information invalidate this assumption. First, Gross[3] has shown that the concentration of HCl rapidly decreases as a function of time while the concentration of CO remains constant. Work at the U. of Michigan[4] dealing with the toxicity of the combustion gases from PVC has shown that when these gases, generated under a number of different conditions are directed into animal testing cages death in each case is related to the carboxyhemoglobin concentration in the blood. There was not evidence of massive tissue damage due to hydrogen chloride nor was there any apparent toxicological synergism between HCl and CO.

This correlation shows that analytical combustion data in the absence of animal testing studies is of little value in determining the toxicity of the combustion products from any material.

In another sense, PVC is superior to the other materials with respect to the evolution of combustion gases. PVC offers an internal warning devise when subjected to burning conditions. The sense of smell is extremely sensitive to HCl but totally insensitive to carbon monoxide.

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Smoke Generation During Combustion

One of the important factors in any fire is the rate of smoke generation. This aspect of flammability is presently undergoing close scrutiny with respect to its effects during a fire. Currently work is in progress in many industrial laboratories in generating an ASTM smoke test (B.F.G. is presently cooperating in this effort).

There was a considerable amount of discussion at the previously mentioned symposium on flammability with regard to smoke generation. The general concensus ~~of opinion~~ is that most synthetic materials are bad in this respect. Indeed, the correlation was noted that the more flame retardant a material is rendered, the more it will generate smoke when subjected to flaming conditions. This is one reason why PVC does generate a considerable amount of smoke when burnt.

Table II contains a summary of smoke data obtained for the rug formulations listed in Table I. Two different values are listed: D_m and $D_{S=16}$. The first value refers to the maximum smoke density recorded for the particular material while $D_{S=16}$ refers to the time (in minutes) to reach a point of 84% light obscuration; i.e., 84% of the available light is obscurred by the smoke. This latter value is of more importance in that it reflects the rate at which "smoke blindness" takes place in a fire. The table shows that with respect to smoke generation (rate and degree) PVC is among the worst under flaming conditions. Under non-flaming or smoldering conditions, PVC is about the same as the other materials.

TABLE II : Smoke Generation From Typical Carpeting Formulations

Composition	D_m F	D_m S	$D_{S=16}$ F	$D_{S=16}$ S
Pile: Modacrylic Backing: Polyester fiber Pad: Polyester Urethane	439	375	0.8	1.2
Pile: Poly(propylene-butylene) Center: Cellulosic Backing: Polyethylene	96	418	1.8	2.0
Wool	123	87	1.6	2.1
Pile: Wool Backing: Polyester Pad: Urethane foam	129	206	2.2	2.0
Modacrylic/Acrylic	350	312	1.2	2.1
Polyester urethane foam (carpet underlay)	58	77	1.9	0.6
Modacrylic/Acrylic	295	254	0.6	1.3
" "	355	327	0.7	2.0
Plasticized PVC/PVA (Flooring Rigid)	342	169	0.6	1.2
Polyamide	51	65	3.2	4.8

The work of Gross has been extended in a more recent study by Gaskill.[3] In this work, the problem of smoke generation is dealt with exclusively. Gaskill has determined the "smoke obscuration indices" (SOI) for a number of natural and synthetic materials. The SOI value is of special interest in that it is a function of the maximum smoke density, the rate of smoke generation and the time to 84% light obscuration.* Table II-A contains a summary of S.O.I. values for a number of different materials. It is again obvious that PVC is among the worst (neoprene and ethylene-propylene are so bad that SOI values can not be calculated!). The data also show the smoke difference when a material is rendered flame retardant. For example, flame retardant acrylic has a SOI of 360 while non-flame retardant acrylic has a value of 10. This same order occurs under both flaming and smoldering conditions. A similar situation also appears in the polycarbonate series. Another correlation to be noted is that for most of the plastic materials in Table II-A, more smoke is generated under flaming conditions than under smoldering conditions.

Based on this work, Gaskill has noted the following conclusions:

1) "Woods and most polymeric materials pyrolitically degrade, yielding smokes that are dense to very dense. Ventilation will tend to clear the smoke but in most cases it will not reduce the intensity to the point of satisfactory visibility.

2) Woods and those polymeric materials that burn cleanly will under the influence of heat and flame yield smokes of somewhat less density. With fire retardance incorporated into the polymer....heat and flame generally produce very dense smoke and they do this rapidly.

3) Urethane foams under flaming or non-flaming exposures generally yield dense smokes and with few exceptions obscuration occurs in a fraction of a minute.....

*The higher the number, the greater the smoke density.

TABLE II-A : Smoke Obscuration Indices For Various Materials

	Flaming	Smoldering
Hardwood	5	25
Red Oak	1	35
White Oak	4	80
Acrylic (fire retardant)	360	25
Acrylic	10	3
Polyethylene	20	65
PVC (rigid)	2400	70
Polystyrene	900	21
Nylon	1	1
Neoprene (self-extinguishing)	a	a
Ethylene-Propylene	a	a
Silicone rubber	105	90
Polycarbonate (self-extinguishing)	a	0
Polycarbonate (non-self-extinguishing)	60	0
Urethane rubber (TDI-ester)	50	5

a - value too high to be calculated

4) The few data we have accumulated to date on the specific components of smoke suggest only that, where compounds such as HCN and CO are present, smoke is likely to be more toxic than if the cyanide were absent. Work done at Duke University indicates a synergistic toxological effect of these two compounds in combination. One might suspect the presence of HCl combined with CO would not be beneficial."

Flammability of Carpeting Formulations

The above considerations (smoke, generation of toxic gases) are important with respect to flammability but of prime importance is the internal flame retardancy of the material. The FFA of 1967 deals with this parameter exclusively and any revisions of the act will still relagate the flame retardancy of any material as top priority. Gross in his study of the carpet materials measured the tendency of each to spread flame. These values are reported in terms of total heat released and the maximum rate of heat released (Btu /min.). Table III contains a summary of those values for the carpet materials listed in Tables I and II.

The rate of heat release data are the most significant in that this value is a measure of the flame spread of the material. Noticeably of those tested, PVC has the second lowest rate of all the materials tested and this of course is due to the inherent flame retardancy of PVC.

Of the three measurements carried out by Gross, the heat release data is most significant. It is on this basis that these materials are judged under the Flammable Fabrics Act of 1967. Although the specific test specified by the FFA is not the flame spread test used by Gross, the end result of the test is essentially the same.

Conclusions

The data presented in this paper show that each of the materials listed in Tables I-III differ with respect to the toxicity of their combustion products, the amount of smoke generated during combustion and inherent flame retardancy. The combustion data is of limited use with respect to toxicity due to the lack of animal testing studies. An even more restricting drawback is that the study is valid for only one set of conditions...conditions which do not actually reflect a real fire situation.

It has been stated that the ultimate answer to the problems of smoke and toxic gas generation lies in the development of new concepts in flame retardation. Currently, Goodrich is involved to some extent in this area. A program has been proposed at the Research Center dealing with the mechanism of flame retardation. In addition, BFG is cosponsering a study at Stanford Research Institute involving the mechanisms of burning and flame retardation in polyethylene, PVC and oxygenated polymers. Limited attention will be given to smoke and toxic gas generation. In addition, limited work has been carried out at the Development Center in two areas:

1) the relationship between a polymers' pyrolysis products and flammability, and

TABLE III : Heat Release and Rate of Heat Release From Typical Carpet Material.

	Total Heat Release (Btu)	Maximum Rate Btu/min.
Pile: Modacrylic Backing: Polyester fiber Pad: Polyester urethane	1010	480
Pile: Poly(propylene-butylene) Center: Cellulosic Backing: Polyethylene	560	330
Wool	not given	not given
Pile: Wool Backing: Polyester Pad: Urethane foam	940	140
Modacrylic/Acrylic	not given	240
Polyester Urethane foam (carpet underlay)	140	140
Modacrylic/Acrylic	510	190
" "	800	330
Plasticized PVC/PVA (Flooring Rigid)	420	60
Polyamide	0	0

The threat of future federal legislation in the area of flame retardancy, smoke and toxic gas generation must be construed as a challenge to the vinyl industry. Additional studies complimenting current work at Brecksville and S.R.I. are urgently needed now if B.F.Goodrich is to meet the needs of tomorrow. A research program dealing with this overall problem is now being formulated at the Development Center.

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Subject Correction

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