

# Polymer Flame Retardancy: A New Approach

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**ABSTRACT:** New types of ecologically friendly polymer flame-retardant systems were proposed for Nylon 6,6 and polypropylene [high temperature polymer–organic char former, poly(vinyl alcohol), and silicon–inorganic system]. These systems can act in condensed and gaseous phases. The cone calorimeter and LOI tests indicated the improvement of fire-retardant properties for compositions of flame retardants with Nylon 6,6 and polypropylene in comparison with pure polymers. © 1998 John Wiley & Sons, Inc. *J Appl Polym Sci* 68: 715–725, 1998

**Key words:** carbonization; char former; combustion; ecology; flame-retardant; nylon 6,6; polypropylene; polyvinyl alcohol; silicon

## INTRODUCTION

In the modern polymer industry, different types of flame retardants that are used in polymers are based on halogens (Cl and Br), heavy and transition metals (Zn, V, Pb, and Sb), or phosphorus–organic compounds that may reduce hazards during polymer pyrolysis and combustion, yet may present ecological issues. The use of halogenated flame retardants is still showing an upward trend, but these concerns have started a statistic search for environmentally friendly polymer additives.<sup>1</sup> The European Community proposed restrictions in the use of brominated diphenyl oxide flame retardants because of the potential formation of highly toxic and potentially carcinogenic brominated furans and dioxins during combustion. The International Program for Chemical Safety of the World Health Organization has made several recommendations. Polybrominated diphenyls production and use should be limited because of the concern over high persistency, bioaccumulation, and potential adverse effects at low levels, especially for pentabromodiphenyl oxide. In 1994, the U.S. Environmental Protection Agency released a final draft of exposure and risk assessment of

dioxins and similar compounds.<sup>2</sup> This reassessment finds the risk greater than previously thought. The tetrachlorodiphenyl dioxins and related compounds are potent toxicants in animals with the potential to produce a wide spectrum of effects. Some of these effects may be occurring in humans at very low levels, and some may result in adverse impacts on human health. It was concluded that dioxin should remain classified as a probable human carcinogen. As a result of these trends, it is quite possible that the available selections of polymer flame retardants will be more limited than in the past.

In our research, we have focused on ecologically safe, flame-retardant systems [high temperature polymer–organic char former, poly(vinyl alcohol) (PVA), and [silicon (Si)–inorganic system] that can act: 1) by the formation of a barrier (char)<sup>3</sup> that hinders the supply of oxygen and reducing the thermal conductivity of the material to limit heat transfer; and 2) by trapping the active radicals in the vapor phase (and possibly in the condensed phase).

## High-Temperature Polymer–Organic Char Former

There is a strong correlation between char yield and fire resistance.<sup>4</sup> This follows because char is formed at the expense of combustible gases and because the presence of a char inhibits further

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Reactions (a) and (b), in the above structure, lead to the formation of poly(vinyl ketone) [note (3) from the above structure] as a final product of oxidation of the substrate. Poly(vinyl ketone) was isolated and identified by microanalysis and spectral data.<sup>13</sup>

### Si-Inorganic Systems

According to recent patents, silicone (additives) may be considered as an universal additive to improve the flammability properties of polymers and to decrease the harmful impact on environmental safety.

Our informal preliminary studies have found that the addition of relatively small amounts of Si-inorganic additives (SI) to various polymers significantly reduce their flammability. We have proposed a Si-inorganic system (SI) that, in the first place, inhibits gaseous phase combustion and also affects char formation in the solid phase. This system was incorporated into two different types of polymers: polypropylene and Nylon 6,6.

The proposed mechanism of SI flame suppression is based on gaseous phase inhibition by  $\text{SiCl}_4$  and  $\text{HCl}$ , which can be produced at temperatures above  $300^\circ\text{--}500^\circ\text{C}$ ,<sup>14</sup> exactly the temperatures realized on the surface of burning polymers:

- 350–500°C:
1.  $2 \text{SnCl}_2 + n \text{Si} = 2 \text{Sn} + (n - 1) \text{Si} + \text{SiCl}_4$   
 $\text{SiCl}_4 + 2 \text{H}_2\text{O} = 4 \text{HCl} + \text{SiO}_2$

410°C:

  2.  $2 \text{PbCl}_2 + n \text{Si} = 2 \text{Pb} + (n - 1) \text{Si} + \text{SiCl}_4$

280°–350°C:

  3.  $4 \text{CuCl} + n \text{Si} = 4 \text{Cu} + (n - 1) \text{Si} + \text{SiCl}_4$

300°C

  4.  $2 \text{CaCl}_2 + n \text{Si} = 2 \text{Ca} + (n - 1) \text{Si} + \text{SiCl}_4$

400°C

  5.  $4 \text{FeCl}_3 + n \text{Si} = 4 \text{Sn} + (n - 1) \text{Si} + 3 \text{SiCl}_4$

The Si analogous of the halogenated carbons, in particular, would be expected to be effective flame inhibitors. This hypothesis was confirmed early on, at least with respect to  $\text{SiCl}_4$ . There are, however, significant differences in the behavior of these compounds in the atmosphere. Unlike the halons, the halosilanes readily hydrolyze in moist air.<sup>15</sup> An important consequence is that these compounds will undergo rapid decomposition in the troposphere and would therefore be expected to have correspondingly low potentials for ozone depletion and global warming than halons. Unfortunately, this beneficial property is offset by the

fact that hydrogen halides are produced in the hydrolysis of halosilanes. This effect is so pronounced that the presence of a single Si—halogen bond in a molecule is sufficient to make its vapors corrosive and dangerous to breathe.<sup>16</sup> But, for the SI flame-retardant, Nylon 6,6, this harmful influence is not so important because  $\text{HCl}$  forms in the zone of combustion only at the temperatures above  $500^\circ\text{--}600^\circ\text{C}$  and also takes part in the flame inhibition and reactions with tin (apparently  $\text{SnCl}_4$  formation).

A list of results was published in Lyon's<sup>17</sup> book on fire retardants and in a review article.<sup>18</sup> The tabulated values are the volume percent of inhibitor corresponding to the peak in the flammability curve for a premixed *n*-heptane flame. The value reported for  $\text{SiCl}_4$  was 9.9%. On the basis of this criteria, the flame suppression efficiency of  $\text{SiCl}_4$  is between  $\text{CF}_3\text{Br}$  and  $\text{CCl}_4$ , which were found to have peak values of 6.1 and 11.5%, respectively.

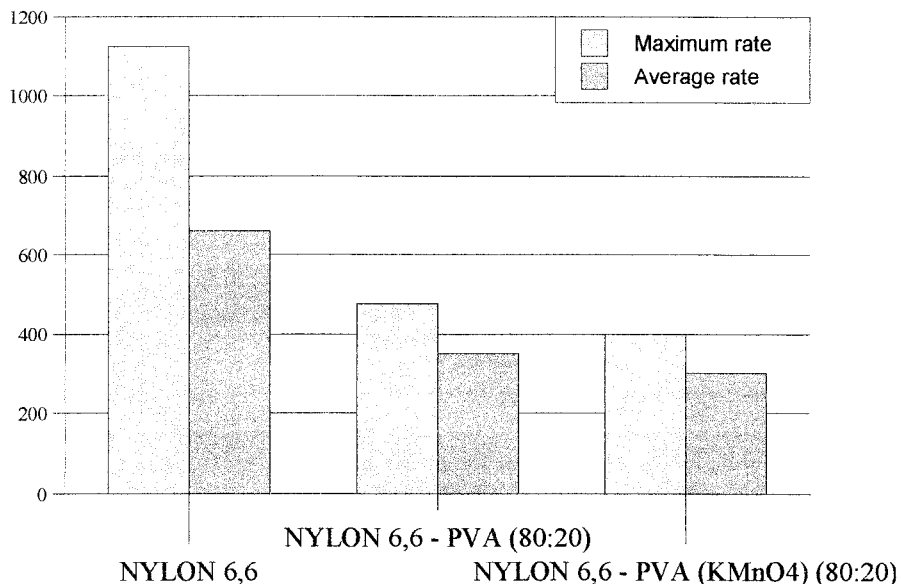
In an independent study, flame velocity measurements were conducted for a series of additives, including some halosilanes and related compounds.<sup>19</sup> The figure of merit was the volume percent of inhibitor required to reduce the burning velocity of a premixed (stoichiometric) *n*-hexane flame by 30%. On this basis, it was determined that the flame inhibition activity of  $\text{SiCl}_4$  (0.56%) was comparable with  $\text{Br}_2$  (0.7%), but considerably more effective than  $\text{CCl}_4$  (1.38%). The hierarchy for inhibition:  $\text{SnCl}_4 > \text{GeCl}_4 > \text{SiCl}_4 > \text{CCl}_4$  was also found to apply to increases in the ignition temperatures of hydrocarbon/( $\text{O}_2 + \text{N}_2$ ) mixtures.<sup>20</sup>

The mechanism by which the halosilanes effect flame inhibition is similar, if not identical, to the well-known halogenated carbons.<sup>18–20</sup>

## EXPERIMENTAL

### Materials

The polymers used in this work were PVA, 99% hydrolyzed, molecular weight 86,000, Nylon 6,6 and polypropylene, isotactic, were supplied by Scientific Polymer Products, Inc. The inorganic additives are potassium permanganate (BA Chemicals Ltd.), Si, metal, 325 mesh, 99% (Aldrich Co.), stannous chloride A.C.S.,  $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$  (REACHIM),  $\text{ZnCl}_2\text{--R}$  (REACHIM),  $\text{MnCl}_2 \cdot 4\text{H}_2\text{O}$  A.C.S. (REACHIM),  $\text{CoCl}_2 \cdot 6\text{H}_2\text{O--R}$  (REACHIM),  $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$  A.C.S. (REACHIM),  $\text{BaCl}_2 \cdot 4\text{H}_2\text{O}$  A.C.S. (REACHIM), and  $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$  A.C.S. (REACHIM).



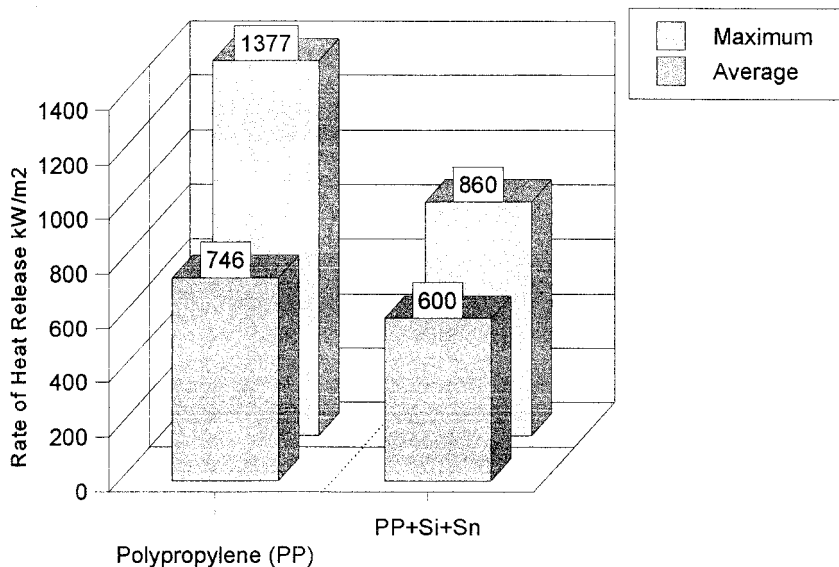
**Figure 1** Rate of Heat Release vs. time for: Nylon 6,6; Nylon 6,6-PVA (80 : 20 wt %); and Nylon 6,6-PVA oxidized by KMnO<sub>4</sub> (80 : 20 wt %); at a heat flux of 50 kW m<sup>-2</sup>.

**Preparation of Samples: Incorporation of Additives**

Blends of Nylon 6,6, PVA, and PVA-ox were prepared in a laboratory blender at room temperature (10 min). The mixed samples were compression-molded at temperatures of 220°–240°C for 10 min. PVA (10 wt % aqueous solution) was oxidized by KMnO<sub>4</sub> in ratio: 5 wt % KMnO<sub>4</sub> : 95 wt % PVA.

PVA was oxidized by KMnO<sub>4</sub> in an aqueous solution. A 10 wt % aqueous solution of PVA was

prepared at 90°C in a laboratory vessel.<sup>21</sup> KMnO<sub>4</sub> (5 wt % of original PVA) was added into the hot aqueous solution of PVA. After a fast reaction (1.5–2 min), the solution became dark brown in color. It was allowed to cool to room temperature. Then, water was removed *in vacuo* at 50°C to yield soft elastic material. This material was heated in an oven for 24 h at 120°C to give a hard plastic material. The resulting material was milled in a laboratory ball mill to produce a dark brown powder.



**Figure 2** Rate of Heat Release for polypropylene composition at a heat flux of 35 kW m<sup>-2</sup>.

**Table I Cone Calorimeter Data of Nylon 6,6–PVA System**

Material (Heat Flux, kW m <sup>-2</sup> )	Char Yield (wt %)	Ignition (Time, s)	Peak Rate of Heat Release (kW m <sup>-2</sup> )	Total Heat Release (MJ m <sup>-2</sup> )
PVA, 20 kW m <sup>-2</sup>	8.8	39	255.5	159.6
PVA, 35 kW m <sup>-2</sup>	3.9	52	540.3	111.3
PVA, 50 kW m <sup>-2</sup>	2.4	41	777.9	115.7
PVA-ox KMnO <sub>4</sub> , 20 kW m <sup>-2</sup>	30.8	1,127	127.6	36.9
PVA-ox KMnO <sub>4</sub> , 35 kW m <sup>-2</sup>	12.7	774	194.0	103.4
PVA-ox KMnO <sub>4</sub> , 50 kW m <sup>-2</sup>	9.1	18	305.3	119.8
Nylon 6,6, 50 kW m <sup>-2</sup>	1.4	97	1,124.6	216.5
Nylon 6,6 + PVA (8 : 2), 50 kW m <sup>-2</sup>	8.7	94	476.7	138.4
Nylon 6,6 + PVA-ox KMnO <sub>4</sub> (8 : 2), 50 kW m <sup>-2</sup>	8.9	89	399.5	197.5

Inorganic additives were mixed with polypropylene powder in a laboratory blender (in ratio of 95% polypropylene: 3% Si : 2% SnCl<sub>2</sub>). Samples were prepared by press-molding at temperatures of 120°–140°C.

Samples for combustion measurements (Nylon 6,6 + SI) were compression-molded at temperatures of 240°–280°C in ratio Nylon 6,6 : Si : MeCl<sub>2</sub> (95 : 3 : 2%, w/w/w).

LOI tests of the samples, as bars (*d* = 4 mm), were conducted according to ASTM-D2863. Self-ignition tests were performed using the ICP Furnace (5–10 mg). Thermal analyses (thermal gravimetric analysis) were performed in air using the DERIVATOGRAPH Q thermoanalyzer (at a heating rate of 10°C min<sup>-1</sup>). Cone calorimeter tests on the polymer samples, as disks (radius 35 mm), were conducted according to ASTM 1356-90 under a heat flux of 20, 30, 35, and 50 kW m<sup>-2</sup>. Each specimen was wrapped in aluminum foil, and only the upper face was exposed to the radiant heater.

**Table II Cone Calorimeter Data of the Heat of Combustion and the Flame-Out Time for Nylon 6,6 Compositions at a Heat Flux of 50 kW m<sup>-2</sup>**

Composition	Flame-Out Time (s)	Average Heat of Combustion (MJ kg <sup>-1</sup> )
Nylon 6,6	512	31.50
Nylon 6,6–PVA (80 : 20)	429	25.15
Nylon 6,6–PVA oxidized by KMnO <sub>4</sub> (80 : 20)	747	29.52

## RESULTS AND DISCUSSION

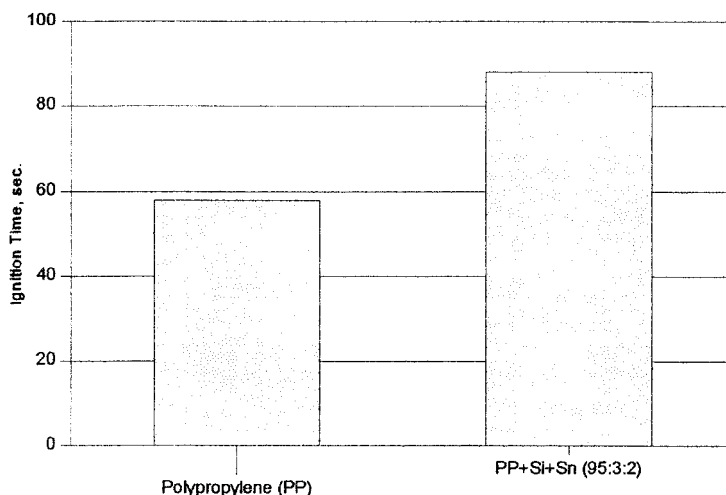
### PVA–Nylon 6,6 System

Preliminary cone tests for PVA and PVA oxidized by KMnO<sub>4</sub> were conducted at heat fluxes of 20, 35, and 50 kW m<sup>-2</sup> (see Table II). It is clearly seen that carbon residue (wt %) and the peak of heat release rate (Peak Rate of Heat Release, kW m<sup>-2</sup>) suggest substantial improvement of fire resistance characteristics for PVA oxidized by KMnO<sub>4</sub>, in comparison with PVA. PVA oxidized by KMnO<sub>4</sub> gives about half the peak of heat release rate (Peak Rate of Heat Release, kW m<sup>-2</sup>) when compared with pure PVA. Even at 50 kW m<sup>-2</sup>, the yield of char residue for PVA oxidized by KMnO<sub>4</sub> was 9.1%. One reason for this phenomenon may be explained by the ability of PVA oxidized by KMnO<sub>4</sub> [poly(vinyl ketone) structures] to act as a neutral (see “1” in structure below) and/or monobasic (see “2” in structure below) bidentate ligand.<sup>9</sup>

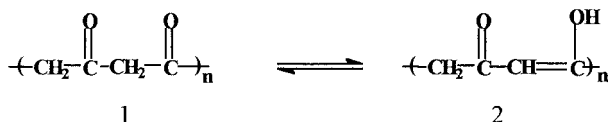
**Table III Cone Calorimeter Data of the Si–Polypropylene System at a Heat Flux of 35 kW m<sup>-2</sup>**

Cone Data	Polypropylene	PP + Si + SnCl <sub>2</sub> (95 : 3 : 2)
Char yield (wt %)	0.0	10.1
Ignition time (s)	62	91
Peak RHR (kW m <sup>-2</sup> )	1,378.0	860.1
Total Heat Release (MJ m <sup>-2</sup> )	332.0	193.7

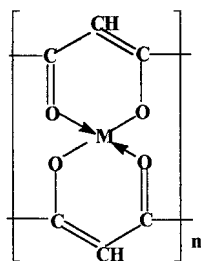
PP, polypropylene; RHR, Rate of Heat Release.



**Figure 3** Ignition time delay for polypropylene composition at a heat flux of 35 kW m<sup>-2</sup>.



The experimental results of others (IR and electronic spectra)<sup>9</sup> provide strong evidence of coordination of the ligand (some metal ions Cu<sup>2+</sup>, Ni<sup>2+</sup>, Co<sup>2+</sup>, Cd<sup>2+</sup>, and Hg<sup>2+</sup>) through the monobasic bidentate mode (see “2” in the structure above). Based on the above, the following structure can be proposed for polymeric complexes:



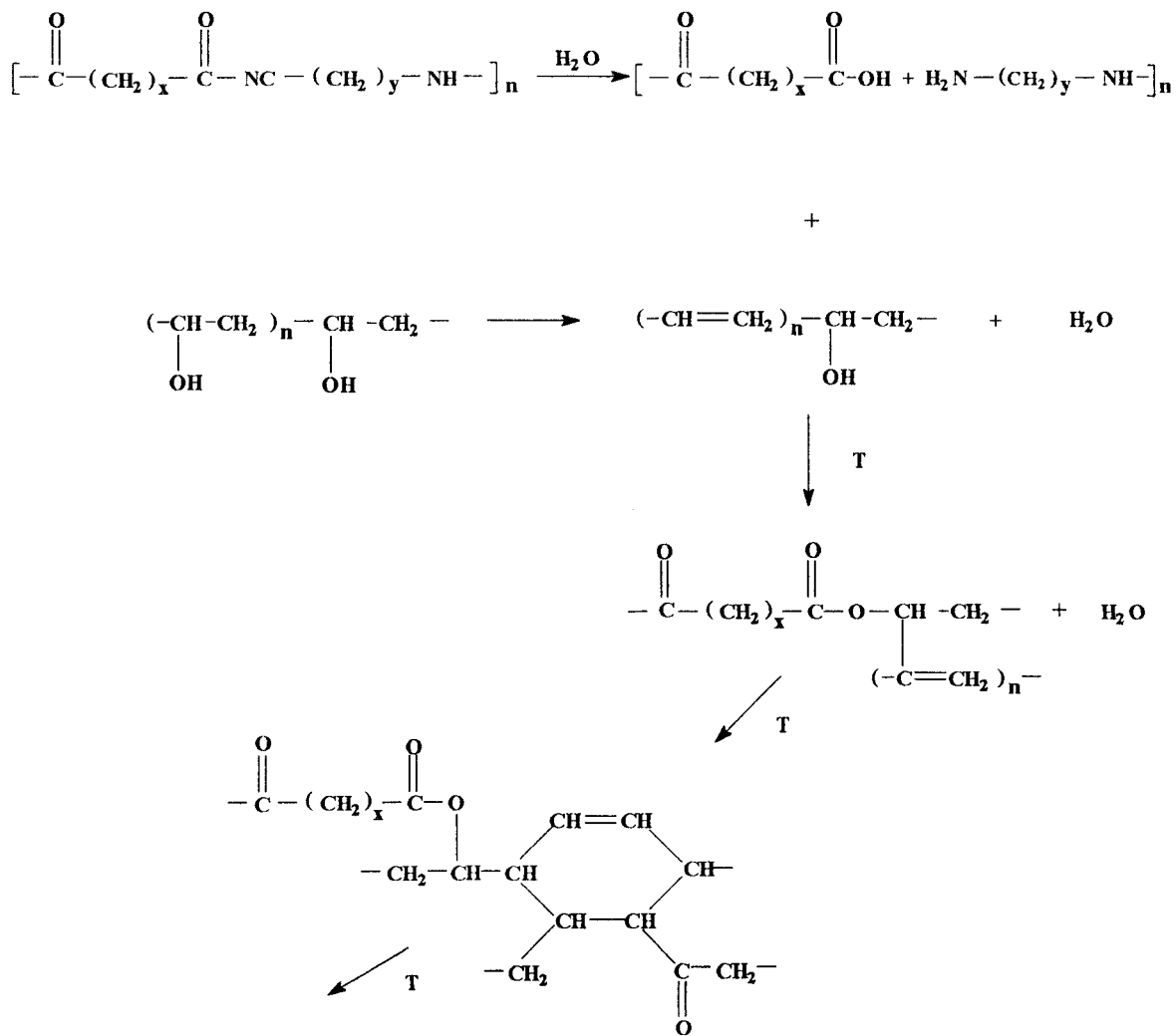
M - metal

The result of elemental analysis of PVA oxidized by KMnO<sub>4</sub> indicates the presence of 1.5% of Mn remaining in this polymeric structure. Thus, we can tentatively suggest that this catalytical amount of chelated Mn structure incorporated in the polymer may provide the rapid high-temperature process of carbonization and formation of char.

The fire tests at 50 kW m<sup>-2</sup> for Nylon 6,6 and PVA (80 : 20%) compositions (typical rate of heat release curves for each sample are shown in Fig. 1) confirmed the assumption of the synergistic effect of carbonization. Each of the individual polymers is

less fire-resistant than their composition. The scheme of “synergistic” carbonization of Nylon 6,6 and PVA is shown herein. Similar trends are observed for Average Heat Release, which was calculated over the total flame-out period (Fig. 2). The sample with PVA oxidized by KMnO<sub>4</sub> displayed even better flame-retardant properties due to the catalytical effect of Mn chelate fragments on the formation of char (Table I). The superior Rate of Heat Release properties of PVA oxidized by KMnO<sub>4</sub> are clearly shown by comparison of the values of Maximum Rate and Average Rate of Heat Release given in Figure 2. However, a less satisfactory correlation is given in the determination of Total Heat Release date (Table I). Although, the cone calorimeter measurements indicate a decrease of Total Heat Release for Nylon 6,6–PVA and Nylon 6,6–PVA oxidized by KMnO<sub>4</sub> in comparison with pure PVA, the sample of Nylon 6,6 with PVA oxidized by KMnO<sub>4</sub> gives a higher value of Total Heat Release than Nylon 6,6 with PVA (Table I). We have qualitatively explained this fact by the influence of a catalytical amount of chelated Mn structure incorporated in the polymer on the smoldering of polymer samples.<sup>9</sup> The flame-out time for Nylon 6,6 with PVA oxidized by KMnO<sub>4</sub> is larger than the flame-out times of Nylon 6,6–PVA and Nylon 6,6 (see Table III). The values of Average Heat of Combustion indicate the exothermal process of smoldering provided by chelated Mn structures (Table II). That is why we have found the approximately equal amount of char yield for Nylon 6,6–PVA and Nylon 6,6–PVA oxidized by KMnO<sub>4</sub> (Table I).

The structure below depicts synergistic carbonization of the Nylon 6,6–PVA blend of volatile products and char.



### Si-Inorganic-Polypropylene-Nylon 6,6 Systems

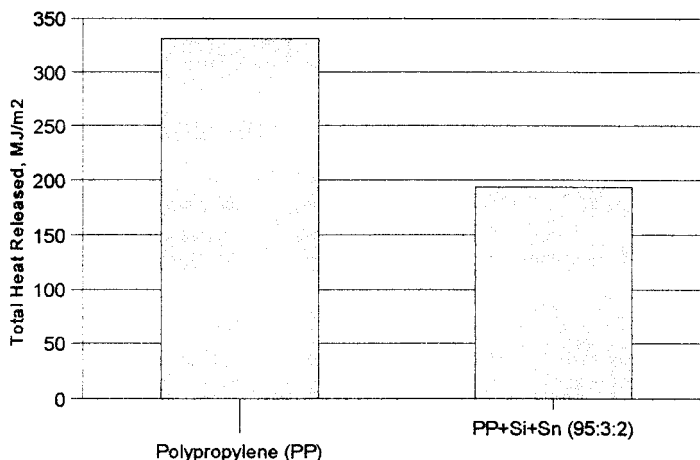
A set of cone calorimeter tests were conducted for polypropylene composition at a heat flux of 35 kW m<sup>-2</sup> (Table III). The flame-retardant composition

included 3 wt % of Si and 2 wt % of SnCl<sub>2</sub>. All cone results indicate an improvement of fire resistance of Si-polypropylene composition in comparison with pure polypropylene (Table III) (Figs. 3 and 4).

**Table IV LOI and Thermal Analysis Data of Nylon 6,6-SI Compositions**

Nylon-SI Compositions (Metal)	LOI (%)	T <sub>fus.</sub> (C)	T <sub>max.</sub> (C)	T <sub>max.</sub> (C)	Char Yield (wt %, 750°C, air)
Nylon 6,6	29	252	430	—	0
Nylon-SnCl <sub>2</sub>	37.5	248	370	448	5.2
Nylon-BaCl <sub>2</sub>	25.5	244	418	—	1.2
Nylon-CaCl <sub>2</sub>	25	245	403	477	3.1
Nylon-MnCl <sub>2</sub>	26.5	255	391	459	1.3
Nylon-ZnCl <sub>2</sub>	26.7	255	388	461	2.1
Nylon-CoCl <sub>2</sub>	26.5	268	419	463	2.7
Nylon-CuCl <sub>2</sub>	27.0	248	438	—	1.1





**Figure 4** Total Heat Release of polypropylene composition at a heat flux of 35 kW m<sup>-2</sup>.

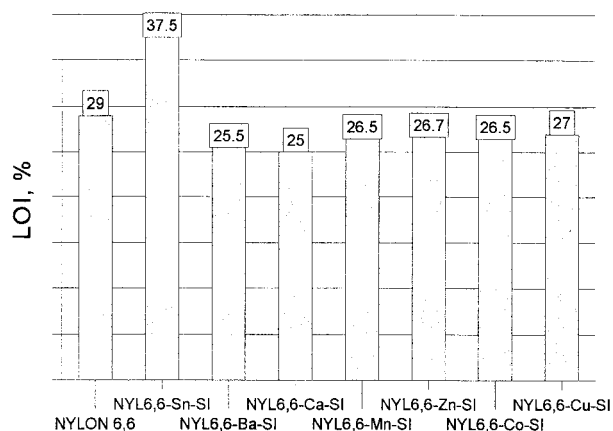
Experimental results of thermal analysis and combustion tests (LOI, self-ignition) of Nylon 6,6–SI compositions are presented in Table V. LOI results clearly showed that incorporation of SnCl<sub>2</sub> + Si (2 : 3 wt %) SI composition in Nylon 6,6 has a substantial flame-retardant effect in comparison with other metal systems (Table IV, Figs. 5 and 6).

Thermal analysis of Nylon 6,6 and Nylon 6,6–SI compositions suggests that it may be possible to provide thermal stabilization of Nylon 6,6 with incorporation of SnCl<sub>2</sub>, CaCl<sub>2</sub>, ZnCl<sub>2</sub>, CoCl<sub>2</sub>, and MnCl<sub>2</sub>. Unlike pure Nylon 6,6 and SI compositions with BaCl<sub>2</sub> and CuCl<sub>2</sub> compositions with

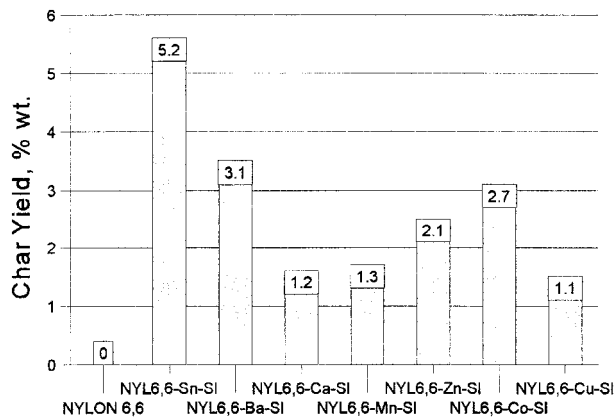
SnCl<sub>2</sub>, CaCl<sub>2</sub>, ZnCl<sub>2</sub>, CoCl<sub>2</sub>, and MnCl<sub>2</sub> have the separate “second” pronounced peak in derivative termograms. This fact can also be confirmed by the difference in the char yield at 750°C (Table V). These observations indicate the process of solid-state crosslinking and char formation provided by SnCl<sub>2</sub>, CaCl<sub>2</sub>, ZnCl<sub>2</sub>, CoCl<sub>2</sub>, and MnCl<sub>2</sub>.

However, the significant flame retardancy effect (LOI = 37.5 and flame ignition time) has only SI compositions with SnCl<sub>2</sub>.

The result of elemental analysis of char from Nylon 6,6–SI composition with SnCl<sub>2</sub> (95 : 3 : 2) indicates the presence of 5% of Sn remaining in this structure. Thus, we suggest that essential



**Figure 5** LOI data for Nylon 6,6 compositions with: SnCl<sub>2</sub>–Si (2 : 3 wt %), BaCl<sub>2</sub>–Si (2 : 3 wt %), CaCl<sub>2</sub>–Si (2 : 3 wt %), MnCl<sub>2</sub>–Si (2 : 3 wt %), ZnCl<sub>2</sub>–Si (2 : 3 wt %), CoCl<sub>2</sub>–Si (2 : 3 wt %), and CuCl<sub>2</sub>–Si (2 : 3 wt %).



**Figure 6** Char yield (wt %) for Nylon 6,6 compositions with: SnCl<sub>2</sub>–Si (3 : 2 wt %), BaCl<sub>2</sub>–Si (3 : 2 wt %), CaCl<sub>2</sub>–Si (3 : 2 wt %), MnCl<sub>2</sub>–Si (3 : 2 wt %), ZnCl<sub>2</sub>–Si (3 : 2 wt %), CoCl<sub>2</sub>–Si (3 : 2 wt %), and CuCl<sub>2</sub>–Si (3 : 2 wt %) (thermal gravimetric analysis, 750°C, air).

**Table V Ignition Time Delays (s) in Nylon 6,6–SI Compositions at 750°C**

Nylon 6,6	Nylon– SnCl <sub>2</sub> –SI	Nylon– MnCl <sub>2</sub> –SI	Nylon– CoCl <sub>2</sub> –SI	Nylon– CuCl <sub>2</sub> –SI	Nylon– BaCl <sub>2</sub> –SI	Nylon– ZnCl <sub>2</sub> –SI
0.5	8.8	8.0	7.6	7.0	6.6	6.2

amount of Sn turns into a gas phase product (apparently SnCl<sub>4</sub>).

As described previously, the hierarchy for inhibition (SnCl<sub>4</sub> > GeCl<sub>4</sub> > SiCl<sub>4</sub> > CCl<sub>4</sub>) was found to apply to increases in the ignition temperatures of hydrocarbon/(O<sub>2</sub> + N<sub>2</sub>) mixtures.<sup>17</sup> It means that SnCl<sub>4</sub> has the highest flame-retardant effectiveness in group IVA elements. We suggest that unique flame retardancy of Nylon 6,6–SI composition (with SnCl<sub>2</sub>), as well as polypropylene composition, can be achieved by allowing SiCl<sub>4</sub>, HCl, and SnCl<sub>4</sub> to act as inhibitors of the gaseous phase combustion. These conclusions are confirmed by self-ignition tests (Table IV).

Data in Table IV show that all MeCl<sub>2</sub>–SI compositions have ignition delay in consecutive order: SnCl<sub>2</sub>–SI > MnCl<sub>2</sub>–SI > CoCl<sub>2</sub>–SI > CuCl<sub>2</sub>–SI > BaCl<sub>2</sub>–SI > ZnCl<sub>2</sub>–SI ≫ Nylon 6,6 (0.5). But only SnCl<sub>2</sub>–SI–Nylon 6,6 composition has an essential flame-retardancy effect (LOI = 37.5), as well as a drastic change (increase) of ignition time delay *versus* T°C.

## CONCLUSIONS

A polymer–organic char former (PVA system) incorporated in Nylon 6,6 reduced the peak rate of heat release from 1124.6 kW m<sup>-2</sup> (for Nylon 6,6) and 777.9 kW m<sup>-2</sup> (for PVA) to 476.7 kW m<sup>-2</sup> and increased the char yield from 1.4% (for Nylon 6,6) to 8.7% due to a “synergistic” carbonization effect. (Cone calorimeter was operated at 50 kW m<sup>-2</sup> incident flux.)

Cone calorimeter data of Nylon 6,6 composition with PVA oxidized by KMnO<sub>4</sub> (Mn–chelate complexes)<sup>13</sup> showed the improvement of Peak Rate of Heat Release from 476.7 kW m<sup>-2</sup> (composition of Nylon 6,6 with PVA) to 399.5 kW m<sup>-2</sup> (composition of Nylon 6,6 with PVA oxidized by KMnO<sub>4</sub>). On the other hand, the cone data indicated the exothermal process of smoldering for composition of nylon 6,6 with PVA oxidized by KMnO<sub>4</sub>. This reaction evidently was provided by chelated Mn structures that increase the Total Heat Release of Nylon 6,6 with PVA

oxidized by KMnO<sub>4</sub> in comparison with Nylon 6,6 with PVA.

A polymeric char former such as PVA and (for example) cellulose systems may present a new type of ecologically safe flame-retardant system.

The flame-retardant binary system of Si (3 wt %) and SnCl<sub>2</sub> (2 wt %) incorporated in polypropylene and Nylon 6,6 acts as an effective inhibitor of gaseous phase flame reactions and may be considered a new type of polymer flame protector based on ecologically friendly SI composition.

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