Flame retardant smoke suppressant coatings for PVC sheathed electrical cables

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ABSTRACT

Fire Spread along electrical cables may be mitigated through application of flame retardant Smol suppressant (FRSS) intumescent coatings as fire protective layers to electrical cables as well as by usir FRSS additives based PVC compositions for sheathing of electrical cables. Metal based organic (MB(complexes of Mo^{+6} and Cr^{+3} were used as FRSS in the present study. FRSS intumescent coatings we applied on cables and their fire performance was evaluated using national and international standa procedures. The coated cables did not show any surface spread of flame on exposure and the generati of smoke was also found to be very low. Plasticized PVC compositions were prepared and found to ha excellent smoke suppression. The limiting oxygen index was found to be fairly high both for the P compositions and the intumescent coatings developed.

Introduction

FIRE is an unexpected event, which is often frightening as well as dramatic. It can lead to loss of life and expensive damage to property and equipment. Large quantities of cables are now being used because of the modern trends in construction, growing need for electronic communication as well as for industrial applications. Modern production facilities also demand long runs of power and control cables all over the plant area. Any fire incidence in the vicinity of the cables may result in the initiation of fire at the cable surface and flame spread along it. Fortunately PVC, the material generally used for electrical power cable sheathing, is among the safer materials in a fire scenario basically because of its chlorine contents that renders it self-extinguishing. When exposed to heat PVC emits hydrogen chloride into the gaseous phase and forms a cross-linked char in the solid phase. HCl reacts with the energy rich, oxygen-based, chain branching free radicals in the gaseous phase which propagate the flame, and thus acts as a chain terminator. The char on the other hand insulates parts of the solid phase; more remote from the fire source; from heat spread as well as reduces oxygen penetration. PVC has been combined with a variety of additives to improve upon the performance of several properties necessary for wires and cable sheathings however, many of these additives result in a compromise on its fire performance. Rapid and unrestrained propagation of fire can be checked either by addition of flame retardant smoke suppressant (FRSS) additives during preparation of PVC sheets or by application of an effective fire retardant coating on PVC sheathed cables. Many FRS for PVC have been reportec erature [1-3]. These can be c fillers, additives and intume ings. Essentially all of th smoke suppressant additiv are either metals or metal and are used only in small Fillers, on the other hand, large quantities and may res vorable mechanical proper the FRSS additives can on during polymer processing, c be applied to the existing tems.

There are two types o which retard the spread o the fire retardant non- i coating, uses additives suc boric acid, antimony trioxide and chlorinated compound not support combustion [1,4-6]

TABLE 1: COMPOSITIONS OF FIRE RETARDANT INTUMESCENT COATINGS

Ingredients	Parts by weight for formulation numbers			
	1	2	3	4
Phosphate	14.0	12.0	15.5	17.0
Amide	12.0	10.0	9.0	11.0
Polyol	10.0	12.0	14.0	8.0
Pigment	5.0	3.0	6.0	4.0
Thickener	0.30	0.30	0.24	0.24
Filler	8.0	9.0	6.0	10.0
Co-polymer emulsion	33.0	35.0	33.0	33.0
Molybdenum complex	2.0	-	-	2.0
Chromium complex	-	2.5	2.0	-
Antifoaming, wetting & antisettling agent	0.20	0.20	0.26	0.16
Water	15.5	16.0	14.0	14.6

type is called fire retardant intumescent coating, which, on heating produce residues, which are swelled by escaping gases. A combustion residue is puffed up in order to produce a tough insulating foam over the surfaces to protect the materials [4,7-11]. These coatings perform better than the non-intumescent ones. Efficacy of fire retardant coatings in improving the burning behaviour of wood and wood based products has been studied by many researchers [1,4-10]. However, sufficient attention has not been paid towards use of suitable coatings to impart fire protection to electric cables.

This paper deals with the fire retardant smoke suppressant metal based organic (MBO) complexes used as FRSS additives in compositions for PVC sheets and in intumescent coatings that provide fire protection to PVC sheathed electrical cables.

Experimental procedure

Preparation of FRSS coatings

A few formulations of flame-retardant smoke suppressant intumescent coatings were prepared by using different types of phosphate amides, polyols, propanediono complex of molybdenum/chromium and binder in different weight ratios. Their compositions are given in *Table 1.* The coatings were prepared by mixing fire retardant smoke suppressant ingredients of 325-400-mesh size with 2-5 percent solution of thickener along with appropriate quantity of antisettling, wetting and anti-foaming agents. Vinyl acetate and vinyl versatate copolymer emulsion (binder) was modified by reacting with dihydroxydimethylol ethylene urea (DHDMEU) and polymeric plasticiser to increase the adhesion to the PVC as well as to improve flexibility of the coating. The required quantity of this modified binder was added to the above contents to make homogenous mixture in order to obtain brush consistency by adding enough water. It was stirred vigorously with a heavy-duty stirrer for one hour. Different thicknesses of FRSS intumescent coating thus prepared were applied with brush on PVC insulated electrical cables.

Preparation of PVC specimens

Pentanedione complexes of molybdenum and chromium (FRSS additives) were synthesized using 2,4 pentanedione (acetylacetone)[12] by replacing the hydrogen of the hydroxyl group of the enol form of the 1,3 diketone by metal thus resulting in the formation of a chelate ring. PVC specimens were prepared by mixing virgin resin with different ingredients, including heat stabilizers

and lubricants such
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Ingredients were use
tities depending on
experiments *(Table*
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TABLE 2: RECIPE AND PROCESSING COND PLASTICIZED POLY (VINYL CHLORIDE) S

Ingredients	Control sample	
Poly (vinyl chloride) resin	100 phr	
Plasticizer	30-90 phr	
Processing aids	2 phr	
FRSS	0 phr	

Processing conditions

Dry blending at room temperature for 20 minutes
Mastication on two-roll mill at 165°C for 10 minu
Compression molding at 175°C

* Phr: parts per hundred parts of resin

TABLE 3: LIMITING OXYGEN INDEX AND SMOKE INDEX OF COATING COMPOSITIONS

Composition	Oxygen Index	Smoke Index
1.	94.4	4.05
2.	92.2	4.22
3.	96.8	3.95
4.	100.0	3.76
Uncoated	42.7	71.53

Flammability

Flammability was studied using the Limiting Oxygen Index (LOI) test as per ASTM D 2863[13]. LOI is the value at which the material just supports flaming combustion. The minimum concentration of oxygen in a mixture of oxygen and nitrogen flowing upward in a test column that will just support combustion is determined under equilibrium conditions of candle like burning. The limiting oxygen index of a material is determined as:

$$LOI = 100 \times \frac{[O_2]}{[O_2]+[N_2]} \quad [1]$$

PVC sheet of size 52 x140 x5 mm was used to determine the limited oxygen index. The specimen was clamped in the specimen holder and mounted vertically in the center of the test column. A tentative initial oxygen concentration was selected to start the set of experiments. The entire top of the specimen was ignited with the help of propane gas. Ignition flame was then removed and the timer started to record the duration of specimen burning. The objective of the test was to determine the minimum oxygen concentration that just allowed the specimen to continue burning either for three minutes or for at least 75 mm the length of the material. The optimum value of oxygen concentration in the gaseous mixture, flowing through the column is termed as limiting oxygen concentration. The observations for different compositions are recorded in *Tables 3* and *4*.

Smoke generation

Smoke generation from FRSS intumescent coatings and the effect of FRSS additives on smoke suppression in PVC compositions was studied using a dynamic method employing LOI apparatus for the combustion of test specimen[14]. Effect of FRSS additives on smoke suppression was estimated in terms of a smoke suppression index. Smoke generation from coatings was estimated by coating PVC sheets 150 x52 x3 mm with 2-mm thick (dry) film of four different compositions and exposing these sheets to the test. Specimens were mounted vertically and subjected to test, for determining the smoke generation, in the Oxygen Index Apparatus. In the dynamic method, specimens are burnt for three minutes at an oxygen concentration that was 2% higher than the LOI value of that specimen. The smoke evolved is allowed to flow through a duct. A He-Ne laser source and receiver are employed to measure the density of smoke flowing through the duct. The smoke generated by a specimen is represented in terms of 'S' the smoke index, which is derived from the area under the optical density profile i.e. the 'time Vs smoke density' curve[15]. Smoke generation from PVC sheathed cables coated with intumescent coatings was measured in terms of smoke index and the results are reported in *Table 3*. Efficacy of smoke suppressant systems is calculated in terms of the Smoke Suppression Index (SS

$$SSI = \frac{S-S_t}{S} \times 10$$

Where S = area und smoke density curve f sample, and

S_t= area under the tim sity curve for the treat

Since the initial weig weight loss for each sa identical, A (Area und smoke density curve f sample/weight loss of A_t (Area under the tim sity curve for the treate loss of the sample) place of S and S_t. Positi (i.e. S > S_t or A>A_t) i in amount of smoke ge a negative value repres Smoke suppression a use of FRSS in PVC reported in *Table 5*.

Char formation

The char formatio compositions was ass oxygen index apparatu fied by the FRSS addi the best results in retardance and smoke exposed to burning c duce char in an LOI duration of exposure v and the oxygen concer

TABLE 4: LIMITING OXYGEN INDEX OF PVC COMPOSITIONS

	Plasticizer								
	DOP						TC		
	Control	1	2	3	4	5	6	7	8
Phr	-	1.0	1.5	2.0	2.5	3.0	1.0	1.5	2
Metal Complex*	-	Mo	Mo	Mo	Mo	Mo	Mo	Mo	M
LOI	27.2	27.4	27.7	28.1	28.6	29.2	32.0	32.5	3
Metal Complex *	-	Cr	Cr	Cr	Cr	Cr	Cr	Cr	C
LOI	27.2	27.6	27.7	27.5	27.8	28.0	31.6	31.8	3

* Metal Based Organic Complex used as FRSS : Mo = Dioxobis (2,4 pentanediono) and Cr = Tris (2,4 pentanediono) chro

TABLE 5: SMOKE SUPPRESSION INDEX OF PVC COMPOSITIONS											
		Plasticizer									
		DOP					TCP				
	Control	1	2	3	4	5	6	7	8	9	10
Phr	-	1.0	1.5	2.0	2.5	3.0	1.0	1.5	2.0	2.5	3.0
Metal Complex*	-	Mo	Mo	Mo	Mo	Mo	Mo	Mo	Mo	Mo	Mo
SSI	-	27.27	28.88	30.90	48.18	57.57	43.00	46.99	52.98	56.30	58.08
Metal Complex*	-	Cr	Cr	Cr	Cr	Cr	Cr	Cr	Cr	Cr	Cr
SSI	-	19.19	24.85	50.30	32.52	9.09	24.59	25.80	26.37	48.57	58.75

* Metal based organic complex used as FRSS : Mo = Dioxobis (2,4 pentanediono molybdenum (VI)
and Cr = Tris (2,4 pentanediono) chromium (III)

was 2% higher than the LOI value for that specimen. A wire gauge was placed about 15 mm below the specimen for collection of char. The specimen and char were carefully weighed before and after burning. The backbone char percentage (BC%) was computed as described by Kroenke[16] and the results reported in *Table 6*.

An apparatus 1200 (H) x 300 (W) x 450 (D) mm having an open front and two clamps to hold the cable specimen in vertical position was employed to study the char formation on cables exposed to fire conditions. In accordance with IEC-332[17] a bunsen burner regulated to give a 125-mm long flame having a blue cone of 40 mm was used as the ignition source. The burner was applied at 45° to the vertically held specimen for 'T' seconds. 'T' is calculated as

$$T = 60 + W/25 \quad [3]$$

Where, W is the weight in grams of the 600-mm long cable specimen. After removal of the ignition flame the period of burning, if any, is recorded in seconds. Later, the specimen surface is wiped clean and the distance of charred or fire affected portion of PVC is measured *(Table 7)*.

In this test we have studied the behaviour of a single cable however, the behaviour of a group of cables may be quite different from it. Thus the flame propagation characteristics of a number of cables laid in a single layer were evaluated employing IEEE-383[18] method. Seven, PVC sheathed multistrand aluminium conductor cables of 17 mm outer diameter coated to an average thickness of 1.5 mm were arranged in a metallic tray of 2440 (L) x305 (W) wide x 76 (D) mm in a single layer. 610 x 610 mm piece of burlap having a unit weight area of 0.3 kg/m^2 was made into a bundle of 100x100 x 150 mm size and soaked in super F multigrade 20W/40 petrol engine oil so as to retain 160 g of it. The soaked burlap was used as igniter and held at the center and in front of the cable tray at a point 600-mm above the bottom of the cable tray. The burlap was set on fire and allowed t naturally. Obs made during the e are recorded in

Results and discussion

The main cons fire and smoke intumescent coat study are amide phosphates propanediono co transition metals plexes used in t study were pro complexes of m and chromium. combination is exposed to fir phate decomposes to proc phoric acid, which acts as a d agent. The polyol is dehydra acid, forming a large amount aceous char that produces bustible barrier to protect the Amide gives off non-flamm causing the foamable carb duce a honeycomb blanket highly effective insulation. on softening forms an expar over the carbonaceous cha the escape of gases produced MBO complexes are chelate tion metals having an org that can cleave at an elevate ture thereby releasing the reactive state for its actio additive. These additives lir ene length, thereby restrictir

TABLE 6: CHAR FORMATION OF FRSS MODIFIED PVC COMPOSITIONS										
		Plasticizer								
		DOP					TCP			
	Control	1	2	3	4	5	6	7	8	9
Phr	-	1.0	1.5	2.0	2.5	3.0	1.0	1.5	2.0	2.5
Metal Complex*	-	Mo	Mo	Mo	Mo	Mo	Mo	Mo	Mo	Mo
BC%	34.79	71.25	74.31	78.07	79.11	61.38	62.94	71.40	73.87	76.4
Metal Complex*	-	Cr	Cr	Cr	Cr	Cr	Cr	Cr	Cr	Cr
BC%	34.79	51.93	58.62	61.43	60.00	56.27	49.13	51.30	53.58	55.7

* Metal Based Organic complex used as FRSS : Mo = Dioxobis (2,4 pentanediono) molybdenum
and Cr = Tris (2,4 pentanediono) chromium (III)

TABLE 7: PERFORMANCE OF COATING AS PER IEC-332

Composition No.	Cable diameter (mm)	Weight of specimen (gm)	Exposure time (second)	Continuation of flame after exposure (second)	Charred length mm	Affected PVC portion (mm)
1.	20	442.8	78	0	80	Nil
2.	20	448.2	78	0	78	Nil
3.	20	440.9	78	0	74	Nil
4.	20	447.0	78	0	70	Nil
Uncoated	17	350.2	74	23	178	168

lecular cyclization and hence resulting in lower amount of smoke generation. Their efficacy in suppressing smoke generation could be ascribed to their better miscibility with the polymer. Essentially all of the effective metal based smoke suppressants appear to work in solid phase resulting in increased char formation and thus reduced flammability of the polymer. They also interfere with the normal degradation pattern of PVC[19]. Smoke retardants act through increase in char formation as well as through change in pyrolyzates. This results in slower burning and lower smoke generation.

Since the maximum effectiveness of MBO additives in suppressing smoke emission is obtained at relatively small concentrations it was decided to use pentanediono complexes of molybdenum (VI) and chromium (III) up to 3 parts per hundred parts of resin (phr) loading. Samples were prepared as described earlier, using both the phthalate (dioctyl phthalate- DOP) and the phosphate (tri cresyl phosphate - TCP) plasticizer at 50 phr. A sample containing 0.0 phr of the additives was used as the control or the reference sample for computation of smoke suppression index (SSI). Experimental results indicate that the oxygen index of coatings varied between 92 and 100. This indicates that these coatings are not likely to catch fire even under the worst conditions, where as the un-coated rigid PVC sheet used as the substrate was found to be a fairly fire retardant one *(Table 3)*. Plasticized PVC sheets modified with FRSS additives also proved to be fairly flame retardant particularly when phosphate plasticizer was used *(Table 4)*.

Smoke generation was found to have reduced very significantly with all the formulations under study *(Table 3)*. For a similar exposure period of three minutes the smoke index was encountered to be sharply decreased from 71.53 for the substrate to as low as 3.76 in case of formulation 4. When the MBO used was dioxobis (2,4 pentanediono) molybdenum (VI) constants decrease in smoke generation i.e. an increase in SSI from 27.27 to 57.57 was observed in case of DOP plasticizer. Comparatively higher values of smoke suppression are observed in the case of samples plasticized with the phosphate plasticizer. The SSI increased from 43.00 to 58.08 when the loading of the molybdenum complex was increased from 1 to 3 phr *(Table 5)*. Samples modified by 1-3 phr of Tris (2,4 pentanediono) chromium (III) showed an overall trend of smoke suppression vis a vis quantity of the complex used for both the DOP and TCP plasticized samples. Phthalate plasticized samples reveal maximum smoke

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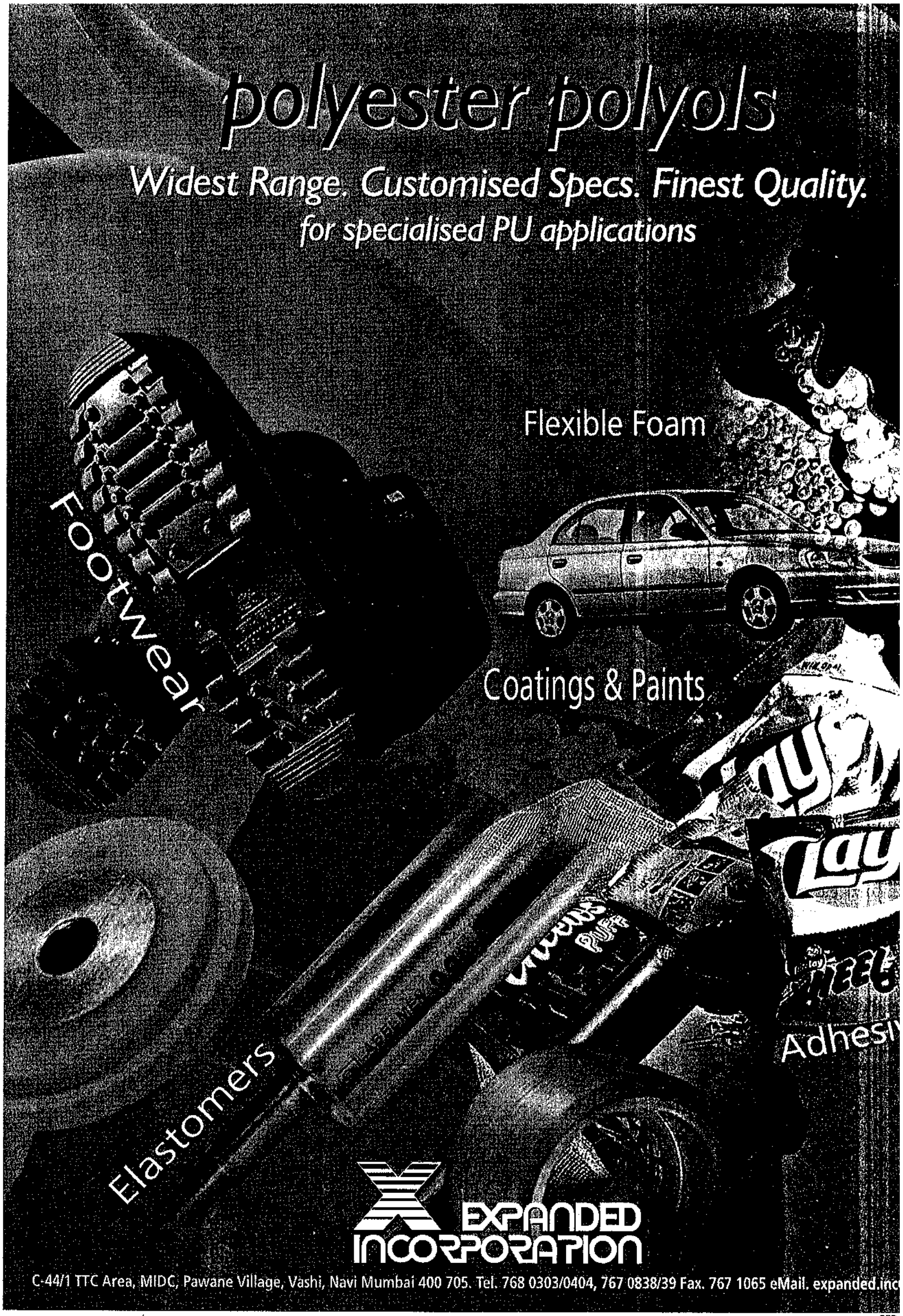
TABLE 8: FIRE PERFORMANCE AS PER IEEE-3

Composition No.	Affected charred length (mm) of differen				
	C_1	C_2	C_3	C_4	C_5
1.	75	338	370	302	314
2.	40	305	350	336	340
3.	24	310	340	285	285
4.	Nil	210	270	165	170
Uncoated	404	862	1050	985	900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specimen charring was noted up to 178 mm and PVC portion was totally damaged up to 168 mm under the same exposure conditions of IEC-332 *(Table 7)*.

It is evident from *Table 8* that the coating prevented the propagation of flame in different cables when they were arranged in a single layer. It is also noted that coated cable did not burn out to the total height of the cable tray above the flame source. Maximum affected charred length was observed in cables number C_3, C_4 and C_5 which were centrally located in cable tray and were in direct touch of heat source. Minimum charred length was observed in adjacent cables number C_1,C_2,C_6 and C_7 which show that coated specimens were retarding flame spread. On the other hand, it can be explained that the charred length was due to direct touch of burlap flame that was measured about 350 to 400 mm height. All the uncoated cable specimens were found to be severely affected and the PVC insulation was found to be totally damaged, however, in case of the coated specimens only exfoliation of coating was observed and no bare wires were seen even after the total burning of burlap igniter.

Conclusions

A few flame retardant smoke suppressant intumescent coatings based on indigenously available chemicals were developed. The coatings applied on PVC sheathed electric cables were found to be quite effective in reducing the flammability and smoke generation from the electrical cables. Fire retardant behaviour (estimated in terms of LOI) and smoke suppressant behavior (estimated as smoke suppression index - SSI) of PVC modified with metal based organic complexes reveal that the additive acts as a FRSS with both the phthalate and the phosphate plasticizers. However, their overall performance is superior in the case of the phosphate plasticized PVC. The char formation by PVC sheets, an indicator of FRSS behaviour, was also found to have increased. However, charring, an indicator of extent of burning for the coated cables was found to have decreased significantly when the intumescent coating, reported herein, was used.

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