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Flame Retardant Smoke Suppressant Coatings for PVC Sheathed Electric Cables

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Flame retardant smoke suppressant intumescent coatings, based on phosphates, amides, polyols, propanediono complex of molybdenum, vinyl acetate and vinyl versatate copolymer emulsion are developed for polyvinyl chloride (PVC) sheathed electrical cables. National and international standard procedures are followed to evaluate the fire performance of the coatings. The coated cables do not show any surface spread of flame on exposure and generation of smoke is found to be well within the limits, in accordance with the ASTM standards. The coatings are found quite effective in reducing the burning behaviour of power cables. Significant improvement in circuit failure time is noted in coated cable specimens.

Introduction

Electrical cables are extensively used in all major industries. These are mostly run through underground cable tunnels, trenches, overhead cable trays and ducts. As the modern production facilities demand long runs of power and control cables all over the plant area, a fire incidence in the vicinity of the cables may result in spread of fire along the entire length of cables laid in trays. Ignition may also result due to short circuit or overheating of cable itself. Any fire incidence to the cables causes extensive damage to the occupancy when it spreads along the electrical cables and through these to other combustible materials. Generation of smoke during burning of electrical cables creates major problems, both for fire control and fire fighting. Fire fighters find it difficult to approach the fire zone, thereby resulting in higher number of fire causalities. In order to prevent vertical or lateral spread of fire through cables, all apertures or openings, which are part of vertical or horizontal partition elements, through which cable or cable trays pass, should therefore be segregated. It is essential that these are subdivided into smaller zones. This may be done by providing fire barriers at different intervals by sealing all the openings with the use of materials that may result in providing adequate fire resistance. Such barriers may not be applicable for the existing electric cable systems. Rapid and unrestrained propagation of fire can also be checked by applying an effective fire retardant coating on electric cables. Application of coating is also possible in the existing cable systems. Various fire retardant coatings have been studied by different workers for finding their efficacy of retardation of the burning characteristics of cellulosic materials such as wood and wood-based products [1-8] Much attention has not been paid towards fire protection of electric cables using suitable coatings. Therefore, there seems to be an ample scope to develop fire and smoke retardant coatings for electric cables.

There are two types of coatings, which retard the spread of fire. One type of coatings, called fire retardant non-intumescent coatings, use additives such as borax, boric acid, antimony trioxide, zinc oxide and chlorinated compounds which do not support combustion[1-4]. The other type is called fire retardant intumescent coatings, which, on heating produce residues, which are swelled by escaping gases. A combustion residue can be efficiently puffed up in order to produce a tough insulating foam over the surfaces to protect the materials [1,5-9]. These coatings perform better than simple fire retardant coatings. This paper deals with the development and evaluation of fire and smoke suppressant intumescent coatings for electric cables.

Experimental Procedure

(i) *Preparation of Coating*

A few formulations were prepared by using different types of phosphate amides, polyols, propanediono complex of molybdenum and binder in different weight ratios. Their compositions are given in Table 1. The coat-

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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	35.5	33.0	33.0
Molybdenum complex	2.0	2.0	2.0	2.0
antifoaming, wetting and antisettling agents	0.20	0.20	0.26	0.16
Water	15.5	16.0	14.0	14.6

Table 2—Physical Properties of Coatings

Colour	Off white
Odour	Faint odour
Specific gravity	1.2 - 1.36
pH	6 - 8
Flexibility (As per IS : 10810)	No cracking observed
Solid binder ratio	2.6 - 2.8
Volatile contents	30 – 32 per cent
Covering capacity	2.25 kg/m^2

ings were prepared by mixing fire retardant smoke suppressant ingredients of 325-400 mesh size with 2-5 per cent solution of thickener along with appropriate quantity of antisettling, wetting, and antifoaming agents. Vinyl acetate and vinyl versatate copolymer emulsion (binder) was modified by reacting with dihydroxy-dimethylol ethylene urea and polymeric plasticizer 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 heavyduty stirrer for 1 h . The fire retardant smoke suppressant intumescent coating thus prepared is applied with brush on PVC insulated electrical cables.

(ii) *Evaluation of Coating*

The standard procedures were followed for determining physical properties such as colour, specific gravity, flexibility of coatings, and are recorded in Table 2.

The fire performance and smoke generation characteristics were also studied, using standard procedures. In order to obtain effective fire retardancy the cables were coated with different amounts of coating to achieve various coating thickness. The effect of coating thickness on fire performance is also studied.

Determination of Circuit Failure Time (as per IEC – 331 Method)

Three- and- a- half- core aluminum conductor PVC insulated armored cable specimens of length 1200 mm and having an outer diam of 31 mm were used to determine the circuit failure time. The cables were coated with different amounts of coating to achieve 1.0 mm to 3.0 mm dry coating thickness. 100 mm sheath of outer covering of the cable was removed from each end of the specimens. At one end of the cable the conductor wires were suitably connected for electrical connections and at the other end the exposed cores were spread apart to avoid contact with each other. The cable specimen was held horizontally by means of suitable clamps at each end of the sheathed portion. The middle portion of cable was supported by two metal rings, placed approximately 300 mm apart and all the metal part of the supporting apparatus were properly earthed. The cores of the cable under test were connected to separate phases for obtaining three sets of connections to the three phases. Adjacent conductors were connected to different phases. The test was carried out in a chamber provided with proper means for disposing of gases resulting from the burning cable. A Tubol type gas burner of 610 mm long was used to ignite the specimen. A thermocouple was fixed, parallel to the burner and 75 mm above it to measure the temperature of the flame. The liquefied petroleum gas was used as a fuel. The air supply and flame height were so adjusted that a temperature of 750°C was obtained throughout the test.

As per IEC-331[10], 440 V, 3-phase electric supply was connected to the cable specimen through a 3 A fuse in each phase and a 5 A fuse in the neutral phase which was earthed. The cable remained energized with rated voltage throughout the fire test. The cable was then lowered into the position so that it remained parallel to the burner and its lower surface was 75 mm above the burner. The evaluation was started after verifying flame temperature of 750°C at the height of 75 mm above the burner. The flame and rated voltage were applied continuously till no failure of 3 A fuse took place. A few specimens were exposed at 750°C for 20 min and then re-energized test using rated voltage (as above) was carried out 12 h after to check the continuity of the electric

Table 3—Effect of coating thickness results as Per IEC – 331

Composition No.	Cable diameter (mm)	Coating thickness (mm)	Failure of circuit time (mm)
1	31	1.64	12.60
2	31	1.60	11.80
3	31	1.62	10.80
4	31	1.61	13.90
	31	1.5 - 1.8	14.7
	31	2.0 - 2.2	21.5
	31	2.5 - 2.6	23.0
	31	3.0 - 3.2	27.1
Uncoated	31		5.1

Table 4 —Fire performance of composition - 4 in re-energise test as per IEC-331

Cable diam	Coating thickness (mm)	Time of exposure (mm)	Re-energise test results (min)
31	1.5 - 1.7	20	Fail
31	2.0 - 2.2	20	Fail
31	2.2 - 2.5	20	Pass
31	2.5 – 3.0	20	Pass
31	3.0 - 3.5	20	Pass

cable. Observations, made during the evaluation with different four compositions, are recorded in Table 3. Further the effect of coating thickness on fire performance was also studied but with composition- 4 only. The results for the same are recorded in Tables 3 and 4.

Smoke Generation Test

Tests were carried out in the NBS (National Bureau of Standards) Smoke Density Chamber, as described in ASTM E - 662 [11]. The PVC sheet of size 76 x 76 x 3 mm was used to determine the smoke generation characteristics of the developed coatings. The PVC sheet was coated with four different compositions of about 2 mm dry thickness of coating. The coated specimen was mounted in specimen holder following standard procedure. The above specimen was placed to face the electrically heated radiant energy source, which is mounted within an insulated ceramic tube, and positioned so as to produce an irradiance level of 2.5 w/cm^2 averaged over the central 38.1 mm diam area of the vertically mounted specimen. A photometric system with a vertical light path was used to measure the varying light transmittance as smoke accumulated. The light transmittance measurements were used to calculate the specific optical density of smoke generated during the time period to reach the maximum value. The tests were stopped when maximum light transmission was reached or after 20 min. The uncoated PVC sheet specimen of same size was also evaluated under similar conditions. The following parameters were determined:

D_m = Maximum specific optical density

$t_{90\ per}$ cent = Time where upon 90 per cent of D_m is reached (min)

D_{90S} = Optical density at 90 s

SoN = Sum of specific optical densities at 1 min, 2 min, 3 min and 4 min, respectively, a measure for the rate of smoke development

V_{max} = Maximum rate of smoke generation estimated at every 30 s and expressed in density of smoke/minute (D_s/min)

The results are listed in Table 5.

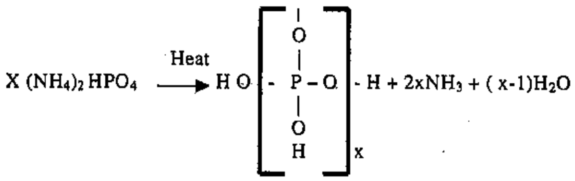
Table 5—Smoke density results in NBS chamber (Smoldering test conditions)

Composition No.	Values of*				
	D_m	$t_{90\ per\ cent}$	D_{90s}	SoN	$V_{max.}$
1	32.0	18.0	2.2	14.6	3.8
2	35.0	16.8	2.8	16.0	4.7
3	34.6	17.5	2.6	15.2	4.35
4	31.2	18.8	2.0	14.1	3.6
Uncoated	632	2.4	127	986	301

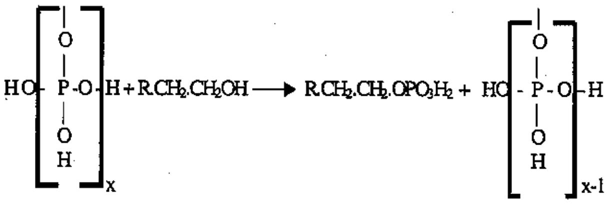
* Lower value of D_m, D_{90S}, SoN, V_{max} and higher value of t_{90} per cent indicate better the performance of a material

Results and Discussion

The main constituents of fire and smoke retardant intumescent coatings under study are amides, polyols phosphates, and propanediono complexes of transition metals. The complex used in the present study was propanediono complex of molybdenum. When this combination is exposed to fire the phosphate decomposes to produce phosphoric acid, which acts as a dehydrating agent. The polyol is dehydrated by the acid, forming a large amount of carbonaceous char that produces a non-combustible barrier to protect the substrate. Amide gives off non-flammable gases causing the foamable carbon to produce a honeycomb blanket resulting in highly effective insulation. The binder on softening forms an expandable skin over the carbonaceous char to resist the escape of gases produced by amides. Smoke retardants acted through increase in char formation as well as through change in pyrolyzates. The resulting species are abundant in CO and CO_2 instead of volatile vapours, which help in accelerating the combustion process. This results in slower burning and lower smoke generation. All these reactions take place within the coating, thereby protecting the material from heat. The above mechanism may be expressed by Eqs (1-4) [1,9,12]

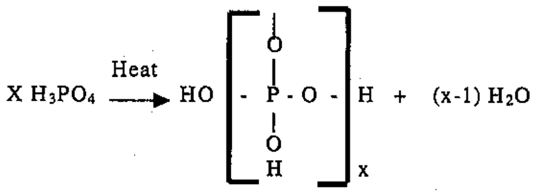


... (1)



... (2)

$$R.CH_2.CH_2OPO_3H_2 \xrightarrow[\text{Heat}]{\text{More}} R.CH = CH_2 + H_3PO_4 \quad \ldots (3)$$



... (4)

It is evident from the fire tests, that paint formulations under the discussion are very effective in reducing the burning characteristics of electric cables. Circuit failure time was also increased from 3.35 min to 13.9 min in coated specimens (Table 3). The studies have also revealed that the fire performance is also dependent upon thickness of the coating. It is observed from Table 4 and 5 that cable of 31 mm diam required coating thickness of above 2.2 mm to pass re-energize test after 20 min exposure as per IEC-331. The specimen was considered as 'Pass' in which no failure of any 3 A fuse occurred during exposure and after 12 h, in re-energize test, cable also withstood 3 phase 440V electric supply. Those specimens, which could not meet above criteria, were considered as 'Fail'. The cable coated with about 2.2 mm dry coating thickness failed in re-energize test as it could not withstand rated voltage after 12 h. However, circuit failure time was increased significantly in cable specimen coated with different compositions to 1.6 mm coating thickness tested as per IEC-331 (Table 3). The smoke retardants (based on pentanediono complex of molybdenum) studied were also found quite effective in reducing the rate and amount of smoke formed. The value of $t_{90\ \text{per cent}}$ was increased from 2.4 min to 18.8 min indicating that the smoke generation time was increased significantly on using these coatings. Further, it was also found that during the standard exposure the amount of smoke was noted in the range of 31.2 to 35 D_m, whereas the value for uncoated specimen was 632 D_m, when evaluated as per ASTM E-662 (Table 5).

Conclusion

A few fire retardant and smoke suppressant intumescent coatings based on indigenously available chemicals are developed which are found to be quite effective in reducing the flammability as well as smoke generation characteristic of electric cables. Circuit failure time is increased significantly in the coated cables. When rated voltage was given to coated cables after exposing them to standard fire conditions the cables were found in workable condition. On exposure the coating intumesises and provide a spongy cellular insulating foam that acts as an effective barrier to the conduction of heat. The formulations were also found quite effective in reducing the production rate and amount of smoke.

References

1 Loyns J W, *The chemistry and uses of fire retardants* (Wiley Interscience, New York) 1970, 256-272.

2 Lewin J M, Atlas S M & Pearce E M, *Flame retardant polymeric materials* (Plenum Press,New York) 1975, 36-37.

3 Baker D S, Flame retarding wood and timber products, *Chem Ind*, **2** (1977) 74-79.

4 Dua A C, Fire retardant paints — effects of various additives in their formulatons, *Paint India*, **32** (No. 7) (1982) 3-5.

5 Bhatnagar V M & Vergnaud J M, Fire retardant paints, *Paint India,* **33** (No.7) (1983) 15-17.

6 Jain J P, Saxena N K & Singh Ilam, Fire retardant surface coating for cellulosoic materials, *Res Ind*, **30** (No. 1) (1985) 20-24.

7 Saxena N K & Gupta D R, Development and evaluation of fire retardant coatings, *Fire Technol,* **26** (No. 4) (1990) 329-341.

8 Saxena N K, Sharma Sunil K and Gupta D R, Fire protection of wood based products by coating, *J Ind Acad Wood Sci*, **21** (No. 2), (1990), 59-62.

9 Smith, T., Flame resistant and intumescent paints and compounds, *Pigm Resin Technol*, **11** (No. 4) (1982), 15-18.

10 IEC –331,Fire resisting characteristics of electric cables, *Int Electro- Tech Commission*, Geneva, Suisse, 1970

11 ASTM E-662, *Standard test Method for specific optical density of smoke generated by solid materials* (American Society for Testing and Materials, Philadelphia, PA 19103, USA) 1979.

12 Clark F B & Lyons J W, The alcoholysis of polyphosphoric acid, *J Am Chem Soc*, **88** (1966) 4401-4405.