

Fire Protection of Electric Cables by Coating

N.K. SAXENA, SUVIR SINGH AND T.P. SHARMA*

*Fire Research Laboratory, Central Building Research Institute,
Roorkee 247 667, INDIA*

ABSTRACT: Fire retardant intumescent coatings based on phosphates, amides, polyols, amino and acrylic binders but free from asbestos and halogenated compounds, have been developed for polyvinyl chloride (PVC) insulated power cables. The fire performance of the coatings has been assessed by employing different procedures as per relevant national and international standards. The cable specimens, with these coatings, did not show any surface spread of flame on exposure to fire. However, the coating swelled to form a spongy, cellular insulating foam, which acted as an effective barrier against the conduction of heat to the surface and to the core of the cable specimen. The coatings were found to be quite effective in reducing the burning behavior of power cables. Significant improvement in circuit failure time is noted in coated cable specimens.

KEY WORDS: intumescent, cable coating, flame propagation, circuit failure time, fire protection, smoke generation, limiting oxygen index.

INTRODUCTION

ELECTRIC CABLES ARE extensively used in all major industries. These are mostly run through underground cable tunnels, trenches, overhead cable trays and ducts. Any fire incidence in the vicinity of the cables may result in initiation of fire at their surface and its spread along the cables laid in trays as modern production facilities demand long runs of power and control cables all over the plant area. Other ignitions may be due to a short circuit or overheating of the cable itself. In a majority of cases, any fire incidence to the cables causes extensive damage to the occupancy when it spreads along the electric cables and through these to other combustible

*Author to whom correspondence should be addressed.

materials. 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 sub-divided into smaller zones. This may be done by providing fire barriers at different intervals by sealing all the openings with the use of materials which may result in providing adequate fire resistance. Such barriers may not be applicable for 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 a coating is also possible in existing cable systems. Various fire retardant coatings have been studied by different researchers to find their efficacy in retarding the burning characteristics of cellulosic materials such as wood and wood-based products [1-10]. However, sufficient 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 retardant coatings for electric cables.

There are two types of coatings which retard the spread of fire. One type of coating, called fire retardant non-intumescent coatings, uses additives such as borax, boric acid, antimony trioxide, zinc oxide and chlorinated compounds which do not support combustion [1-5]. The other type is called fire retardant intumescent coatings, which, on heating, produce residues which are puffed up or 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 [1,7-12]. These coatings perform better than simple fire retardant coatings. This paper deals with the development and evaluation of fire retardant intumescent coatings for electric cables.

EXPERIMENTAL PROCEDURE

A few formulations of fire retardant intumescent coatings for electric cables were prepared by using different types of phosphates, amides, polyols and binders in different weight ratios. Their compositions are given in Table 1. The coatings were prepared by mixing fire retardant ingredients of 325-400 mesh size with 2-5% solution of thickener along with an appropriate quantity of antisetling, wetting and antifoaming agents. The binder was modified by reacting with dihydroxydimethylol ethylene urea (DHDMEU) and polymeric plasticizer at about 40°C to increase the adhesion to the PVC as well as to improve the flexibility of the coating. The polymeric plasticizer and DHDMEU were added slowly to the copolymer emulsion (binder) while stirring at a rate that will not cause aeration. After several hours of stirring, the binder emulsion was allowed to age for at least

Table 1. Compositions of fire retardant intumescent coatings.

Ingredients	Parts by weight for Formulation Nos.			
	1	2	3	4
Phosphate	14.0	12.0	15.5	17.0
Amide	12.0	10.0	8.0	11.0
Polyol	10.0	12.0	14.0	8.0
Pigment	6.0	3.5	5.0	4.0
Thickener	0.30	0.30	0.24	0.24
Filler	8.0	10.0	6.0	10.0
Co-polymer Emulsion	34.0	36.0	31.0	31.0
Amino Resin	—	—	6.0	4.0
Antifoaming, Wetting and Antisettling Agents	0.20	0.20	0.26	0.16
Water	15.5	16.0	14.0	14.6

Table 2. Characteristics of binder.

Composition	Vinyl Acetate and Vinyl Versatate Copolymer Emulsion
Solid Contents	54-56%
Viscosity	4-20 poise
Particle Size (light scattering)	0.65-1.10 μ
pH	4.6-6.0
Film Forming Temperature	About 10°C
Specific Gravity	1.07
Appearance	Milky White Liquid

24 h before use. The required quantity of this modified binder was added to the above contents to make a homogenous mixture in order to obtain brush consistency by adding enough water. It was stirred vigorously with a heavy-duty stirrer for one hour.

The characteristics of copolymer binder are given in Table 2. The fire retardant intumescent coating thus prepared was applied to PVC insulated electric cables of different diameters. In order to obtain effective fire retardancy, the cables were coated with different amounts of coating to achieve different thicknesses of the coating to determine the effect of coating thickness on fire performance. Standard procedures were followed for determining physical properties such as color, specific gravity and flexibility of coatings and are given in Table 3. The fire performance of the coatings was also studied by evaluating flame spread, heat penetration, circuit failure.

Table 3. Physical properties of coatings.

Color	Off White
Odor	Faint Odor
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%
Covering Capacity	2.25 kg/m ²

time, limiting oxygen index and smoke generation characteristics using different standard procedures.

Determination of Circuit Failure Time using the IEC-331 Method

Three and a half core (four core power cable with reduced neutral conductor) aluminum conductor PVC insulated armored cable specimens of length 1200 mm and outer diameters 20 mm and 31 mm were used to determine the circuit failure time. The difference in diameter indicates the electric load carrying capacity of the cable as well as the difference in thickness of the PVC insulation. The 20 mm diameter cable had an outer PVC insulation of about 3 mm while it was noted to be about 4 mm in the case of the 31 mm diameter cable. The cables were coated with a different amount of coating to achieve a 1.0-3.0 mm dry coating thickness. A 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 parts of the supporting apparatus were properly earthed. The cores of the cable under test were connected to separate phases to obtain 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, 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. Liquified petroleum gas was used as fuel. The air supply and flame height were adjusted so that a temperature of 750°C was obtained throughout the test.

As per IEC-331 [13], a 440 V, 3-phase electric supply was connected to the cable specimen through a 3 amp fuse in each phase and a 5 amp 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 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 the flame temperature of 750°C at the height of 75 mm above the burner. The flame and rated voltage were applied continuously until no failure of the 3 amp fuse took place. A few specimens were exposed at 750°C for 1200 s and then a re-energized test using rated voltage (as above) was carried out 12 h later to check the continuity of the electric cable. Observations made during the evaluation with four different compositions are recorded in Table 4. Further, the effect of coating thickness and diameter of cable on fire performance were also studied but with Composition 4 only. The results for the same are recorded in Tables 5 and 6.

Table 4. Results as per IEC-331.

Composition No.	Cable Diameter (mm)	Coating Thickness (mm)	Circuit Failure Time (s)
1	20	1.45	468
2	20	1.45	428
3	20	1.44	494
4	20	1.43	535
Uncoated	20	-	197

Table 5. Results as per IEC-331 (Composition 4).

Cable Diameter (mm)	Coating Thickness (mm)	Circuit Failure Time (s)
20	Uncoated	197
20	1.5-1.7	585
20	2.0-2.2	1060
20	2.5-2.7	1224
20	3.0-3.2	1298
31	Uncoated	269
31	1.5-1.8	818
31	2.0-2.2	1242
31	2.5-2.6	1374
31	3.0-3.2	1609

Table 6. Fire performance as per IEC-331 re-energize test (Composition 4).

Cable Diameter (mm)	Coating Thickness (mm)	Time of Exposure (s)	Re-energize Test Results
20	2.5-2.7	1200	Fail
20	3.0-3.2	1200	Pass
31	2.0-2.2	1200	Fail
31	2.5-2.6	1200	Pass
31	3.0-3.2	1200	Pass

Determination of Flammability Characteristics of Coated Cables using the IEC-332 Method

For certain locations, it is important to use a cable which retards spread of flame in case of fire and self extinguishes fire when the source of heat or fire is removed. To confirm this property, an apparatus, consisting of three side metal screens, 1200 mm high, 300 mm wide and 450 mm deep with open front and closed top and bottom, was used. Two clamps to hold the cable were also provided in the test chamber and were positioned such that the distance between the top and bottom clamp was approximately 500 mm.

A Bunsen burner having a bore of 10 mm and liquified petroleum gas as a fuel was used to determine the flammability of cables. The burner was regulated to give a flame approximately 125 mm long with an inner blue cone approximately 40 mm in length. The coated specimens of size 600 ± 25 mm were placed at a temperature of $60 \pm 2^\circ\text{C}$ until constant weight was achieved. The samples were clamped vertically and positioned in the middle of a three-sided metal screen. The cables were adjusted so that the bottom of the specimen was approximately 50 mm from the base of the screen. The base of the burner was placed at an angle of 45° to the line of sample. When the gas burner was in use, the distance of the burner from the sample was kept such that the inner blue cone of the flame was at a distance of approximately 10 mm along the axis of the flame from the surface of the cable and 475 mm below the lower edge of the top clamp. As per the IEC-332 Standard [14], the flame was applied for a continuous period of T (seconds) derived from the formula.

$$T = 60 + W/25$$

where W is the weight in g of the cable specimen 600 mm in length.

Table 8. Fire performance as per IEEE-383.

Composition No.	Affected Charred Length (mm) of Different Cable Nos.						
	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇
1	75	338	370	302	314	215	100
2	40	305	350	336	340	245	80
3	24	310	340	285	285	205	46
4	Nil	210	270	165	170	Nil	Nil
Uncoated	404	862	1050	985	900	805	410

It gave an exposure of about 30 min. Observations made during the evaluations are recorded in Table 8.

Limiting Oxygen Index

Limiting Oxygen Index (LOI) is the value at which the material just fails to support flaming combustion. The test reveals the intrinsic flammability of a material but tells very little about its role in propagating a fire from one place to another. 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 according to ASTM D-2863 [16]. The limiting oxygen index of a material is determined as:

$$LOI = 100 \times \frac{O_2}{O_2 + N_2}$$

where O_2 and N_2 are the volume concentrations of each gas in the air stream.

A Stanton Redcroft FTA flammability unit was used to determine the oxygen index of different compositions. The apparatus was calibrated for 0% oxygen and 100% oxygen levels. A PVC sheet of size $52 \times 140 \times 5$ mm was used to determine the limiting oxygen index. A coating of about 2 mm dry thickness was applied to the PVC sheet. Thus, the prepared 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. The ignition flame was then removed and the timer started to record the duration of the specimen burning. The uncoated specimen of the PVC sheet was also evaluated under the same conditions using the same set up.

Table 9. Limiting oxygen index of compositions.

Composition	% Oxygen
1	94.4
2	92.2
3	96.8
4	100
Uncoated	42.7

The objective of the test was to determine the minimum oxygen concentration which just allowed the specimen to continue burning either for 3 min or for at least 75 mm of the length of the material. If the concentration of oxygen was on the low side, it was raised if the burning of the specimen extinguished before meeting either of the criteria (that it either burns for more than 3 min or for a minimum burning length of 75 mm), whichever of the two conditions was satisfied earlier.

The oxygen concentration may be on the higher side and needs to be reduced if the specimen continues to burn beyond 75 mm or 3 min. The optimum value of oxygen concentration in the gaseous mixture, flowing through the column, is termed the limiting oxygen concentration. The observations recorded with different compositions are given in Table 9.

Smoke Generation Test

Tests were carried out in the NIST (National Institute of Standards and Technology) Smoke Density Chamber as described in ASTM E-662 [17]. A PVC sheet of size $76 \times 76 \times 5$ mm was used to determine the smoke generation characteristics of 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 a specimen holder following the 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 diameter 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 the maximum light transmission was reached or after 20 min. An uncoated PVC sheet

Table 10. Smoke density results in NIST chamber (Smoldering test conditions).

Composition No.	Values of ^a				
	D_m	$t_{90\%}$	D_{90s}	SoN	V_{max}
1	34.4	16.0	2.8	15.8	4.0
2	35.9	16.8	3.0	16.2	4.8
3	33.6	17.2	2.5	15.0	4.3
4	32.0	18.4	2.2	14.6	3.8
Uncoated	608	2.8	105	974	294

^aLower value of D_m , D_{90s} , SoN, V_{max} and higher value of $t_{90\%}$ indicate better performance of a material.

specimen of the same size was also evaluated under similar conditions. The following parameters were determined:

- D_m maximum specific optical density
- $t_{90\%}$ time whereupon 90% of D_m is reached (minute)
- D_{90s} optical density at 90 s
- SoN sum of specific optical densities at 1 min, 2 min, 3 min and 4 min, 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 per min (D_s /min).

The results are listed in Table 10.

Moisture Absorption Test

The moisture absorption of the coatings was determined after applying the paint on smooth and dried glass plates. The coated specimens were dried at 60°C for 72 h followed by drying over calcium chloride. The specimens were then placed at 60%, 80% and 96% controlled relative humidities for 72 h. The moisture pickup by coatings is given in Table 11. In order to increase the water repellency of coatings, additives Finawax-C' (FWC) and Fynex PE-100 (FPE), which are proprietary products of Fine Organics Limited, Ghatkopar (E), Mumbai, India, were studied with paint compositions. The effect of additives on moisture absorption by coating was studied following the above procedure. The results with respect to moisture absorption at different relative humidities are reported in Table 11. The effect of the additives to the coatings on fire performance of electric cables was also studied. The additives listed in Table 12 were added to Composition 4. A 20 mm diameter cable was coated up to 3.0 mm dry

Table 11. Moisture absorption by coatings.

Composition No. ^a	Additive	Percent Moisture at Relative Humidity		
		60%	80%	96%
1	--	2.02	7.08	15.12
2	--	1.86	6.85	14.95
3	--	2.00	6.08	14.32
4	--	1.96	5.62	13.72
4	FWC-6%	1.84	5.22	12.28
4	FWC-8%	1.20	2.40	7.20
4	FWC-12%	1.18	2.25	7.08
4	FPE-6%	1.90	5.46	13.02
4	FPE-8%	1.62	3.86	8.70
4	FPE-12%	1.18	3.09	8.10

^aData with other compositions are quite similar to this.
 Note: FWC Finawax-C; FPE Fynex PE-100.

Table 12. Fire performance of cables before and after water immersion test (Composition 4^a).

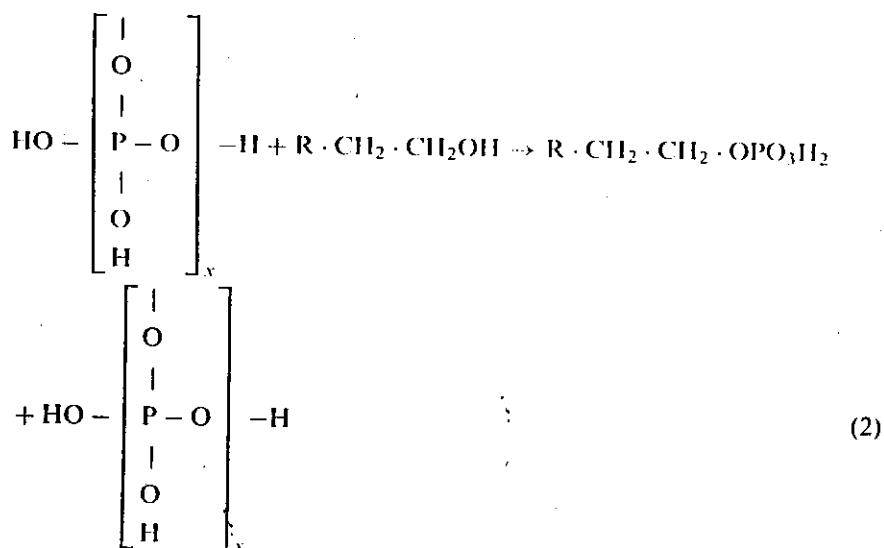
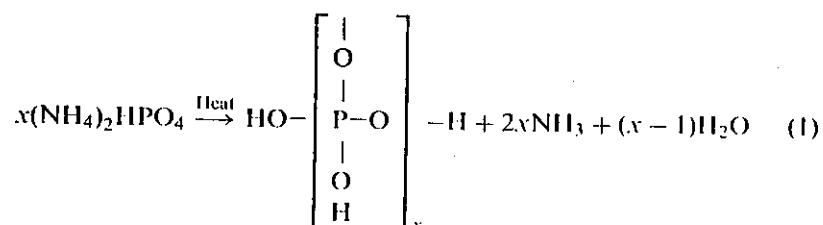
Additives	Immersion Time (h)	Circuit Failure Time as per IEC-331 (s)
--	0	1298
FWC-8%	0	1298
FWC-10%	0	1296
FWC-12%	0	1277
FPE-8%	0	1273
FPE-10%	0	1267
FPE-12%	0	1246
--	168	1209
FWC-8%	168	1287
FWC-10%	168	1291
FWC-12%	168	1274
FPE-8%	168	1215
FPE-10%	168	1262
FPE-12%	168	1228

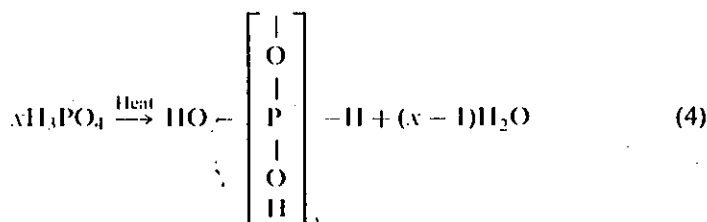
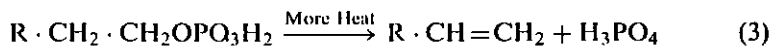
^aData with other compositions are quite similar to this.

coating thickness. The coated electric cables were subsequently immersed in water for 168 h. Cable specimens were taken out and then dried completely at about 60-65°C for 7 days. The fire performance of electric cable before and after immersing in water for 168 h was determined following the IEC-331 method. The results are recorded in Table 12.

RESULTS AND DISCUSSION

The main constituents of fire retardant intumescent coatings under study are amides, polyols and phosphates. 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 noncombustible barrier to protect the substrate. Amide gives off non-flammable gases causing the foamable carbon to produce a honeycomb blanket resulting in a highly effective insulation. The binder on softening forms an expandable skin over the carbonaceous char to resist the escape of gases produced by amides. All these reactions take place within the coating, thereby protecting the material from heat. The above mechanism may be expressed by the following equations [1,11,18].





It is evident from the fire tests that paint formulations under discussion are very effective in reducing the burning characteristics of electric cables. No flame spread or flaming was observed during exposure in coated specimens. Circuit failure time was also increased from 197s to 535s in coated specimens (Table 4). The studies also revealed that the fire performance is dependent on cable diameter and thickness of the coating.

It is observed from Tables 5 and 6 that for 31 mm diameter cables, a coating thickness above 2.5 mm is required to pass the re-energize test after a 1200 s exposure as per IEC-331 while, in the case of the 20 mm diameter cable, about a 3.0 mm thickness of cable coating is required to pass the re-energize test. The specimen was considered to have passed when no failure of any 3 amp fuse occurred during the exposure and, after 12 h, in the re-energize test, the cable also withstood a 3 phase 440 V electric supply. Those specimens which could not meet the above criteria, were considered to have failed. The 31 mm diameter cable coated with about 2.2 mm dry coating thickness and 20 mm diameter cables coated up to 2.7 mm thickness, failed the re-energize test as they could not withstand the rated voltage after 12 h. However, the cable specimen coated with different compositions to 1.5 mm coating thickness, tested as per IEC 332, were extinguished when the flame source was removed. No heat penetration was noted in the coated specimen and only charring was observed on the coating up to the 80 mm height where the source of flame was applied. PVC was found to be unaffected underneath the coating.

On the other hand, in the uncoated specimen, charring was noted up to 178 mm and the PVC portion was totally damaged up to 168 mm under the same exposure conditions of IEC 332 (Table 7). The results of the coated and uncoated 17 mm diameter cables, evaluated as per IEEE-383, are shown in Table 8. 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 from Table 8 that coated cable did not burn

out to the total height of the cable tray above the flame source. The maximum affected charred length was observed in cable numbers C₃, C₄ and C₅ which were centrally located in the cable tray and were in direct contact with the heat source. The minimum charred length was observed in adjacent cable numbers C₁, C₂, C₆ and C₇ which show that coated specimens retarded flame spread. On the other hand, it can be explained that the charred length was due to the direct touch of the burlap flame which was measured at about the 350 to 400 mm height. It is also interesting to note that, in coated specimens no bare wires were seen after the total burning of the burlap igniter according to IEEE-383. Only exfoliation of the coating was observed in such coated cables. However, in the case of uncoated cable specimens, all the cables were found to be affected and the PVC insulation was totally damaged.

Further experimental results for the Limiting Oxygen Index, compiled in Table 9, show that the coating prepared with Composition 4 did not burn even if the oxygen concentration was raised to 100%. The limiting oxygen index of other compositions were noted to be in the range of 92-96% which is also very high in comparison to the uncoated specimen. The paint formulations under study were also found to be quite effective in reducing the rate and amount of smoke formed. The value of $t_{90\%}$ was increased from 2.8 min to 18.4 min indicating that the no-smoke generation time was six times greater when using these coatings. Further, it was also found that, during the standard exposure, the amount of smoke was noted in the range of 32-36 D_m whereas the value for the uncoated specimen was 608 D_m when evaluated as per ASTM E-662 (Table 10). It is also established experimentally that the paint film resisted the effect of humidity up to 96% and did not detach itself from the surface thereby showing good adhesion. Moisture pickup by the coatings at higher humidities was noted to be only about 15%.

It is observed from Table 12 that the fire performance of coated specimens was slightly reduced when they were tested after immersion in water for seven days. This may be due to the water soluble characteristics of a few chemicals used in the paint formulation. After immersion in water, the amount of such ingredients may be reduced thereby slightly affecting fire performance. The additives Finawax-C and Fynex PE-100 (wax emulsions) were studied in order to enhance the water repellency and improve the fire performance of coated cables after the water immersion test.

It is observed from the studies that the addition of 8% Finawax or Fynex to coatings reduced the moisture pick-up by about 47 and 36% respectively at 96% relative humidity (Table 11). No change in fire performance was noted with Finawax at this concentration when cables were tested before immersing in water while, with Fynex, the fire performance was slightly

reduced. It is also noted that the fire performance determined after immersing the coated cables in water for 168 h was slightly improved when 8% Finawax or Fynex was used in Combination 4. The circuit failure time was noted to be 1287 s, and 1215 s with Finawax and Fynex, respectively. On the other hand, without the addition of either of these two additives, circuit failure time was recorded 1209 s after the water immersion test (Table 12). Table 11 also reveals that when these additives are used in higher concentration (12%), the moisture absorption characteristics of coatings are slightly improved. The moisture picked up by the coating was reduced to 49 and 41% with 12% Finawax and Fynex, respectively at 96% relative humidity and the fire performance was slightly reduced with the 12% additives when coated cables were tested before immersing in water.

Circuit failure time was noted to be 1277 s with Finawax and 1246 s with Fynex, however, it was noted to be 1298 s without any additive. On the other hand, an improvement in fire performance was noted when coated cables were tested after immersing in water for 168 h. Circuit failure time was increased from 1209 s to 1274 s and to 1228 s with 12% Finawax and Fynex, respectively (Table 12). It is evident from Tables 11 and 12 that additives under study are found to be quite effective in improving the water absorption property of the coating thereby enhancing the fire performance of coated cable after immersing in water for 7 days. Further, it is also observed from data obtained that the additive Finawax was found to be more effective than Fynex. It is clear from the experimental data that the use of these additives would be quite useful when coated specimens are used at higher relative humidity.

CONCLUSION

A few fire retardant intumescent coatings based on locally available chemicals have been developed which are found to be quite effective in reducing the flammability of electric cables. Circuit failure time is increased significantly in the coated cables. When rated voltage was applied to coated cables after exposing them to standard fire conditions, the cables were found to be in workable condition. The specimens with these coatings showed neither surface spread of flame nor any heat penetration. After exposure, the coating intumesces and provides a spongy cellular insulating foam that acts as an effective barrier to the conduction of heat. The addition of Finawax and Fynex increases the water repellency of the coatings. The formulations were also found to be quite effective in reducing the production rate and amount of smoke.

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REFERENCES

1. Lyons, J.W., *The Chemistry and Uses of Fire Retardants*. New York: Wiley Interscience, 1970, pp 256-272.
2. Lewin, J.M., Atlas S.M. and Pearce, E.M., *Flame Retardant Polymeric Materials*. New York: Plenum Press, 1975, pp 36-37.
3. Baker, D.S., "Flame retarding wood and timber products", *Chemistry and Industry*, Vol. 2, 1977, pp 74-79.
4. Baker, D.S., "Flame spread and flame retardant treatments", *Chemistry and Industry*, Vol. 14, 1981, pp 485-490.
5. Dua, A.C., "Fire retardant paints - effects of various additives in their formulations", *Paint India*, Vol. 32, No. 7, 1982, pp 3-5.
6. Mishra, J.P. and Srivasamban, M.A., "Fire retardant coatings", *Paint India*, Vol. 29, No. 6, 1979, pp 21-26.
7. Bhatnagar, V.M. and Vergnaud, J.M., "Fire retardant paints", *Paint India*, Vol. 33, No. 7, 1983, pp 15-17.
8. Jain, J.P., Saxena, N.K. and Singh, Ham., "Fire retardant surface coating for cellulosic materials", *Research and Industry*, Vol. 30, No. 1, 1985, pp 20-24.
9. Saxena, N.K. and Gupta, D.R., "Development and evaluation of fire retardant coatings", *Fire Technology*, Vol. 26, No. 4, 1990, pp 329-341.
10. Saxena, N.K., Sharma, Sunil and Gupta, D.R., "Fire protection of wood based products by coating", *J. Ind. Acad. Wood Sci.*, Vol. 21, No. 2, 1990, pp 59-62.
11. Smith, T., "Flame resistant and intumescent paints and compounds", *Pigment and Resin Technology*, Vol. 11, No. 4, 1982, pp 15-18.
12. Smith, C.A., "Review of flame retardant and intumescent paints and compounds", *Pigment and Resin Technology*, Vol. 13, No. 5, 1984, pp 9-10.
13. IEC-331, Fire resisting characteristics of electric cables. International Electro-Technical Commission. Geneva, Switzerland, 1970.
14. IEC-332, Tests on electric cables under fire conditions. Part 1: test on a single vertical insulated wire or cable. International Electro-Technical Commission. Geneva, Switzerland, 1979.
15. ANSI/IEEE-383, Standard for type test of class II electric cables, field splices and connections for nuclear power generating stations. The Institute of Electrical and Electronics Engineers Inc., New York, 1974.
16. ASTM D-2863, Standard methods for measuring the minimum oxygen concentration to support candle-like combustion of plastic (oxygen index), American Society for Testing and Materials, Philadelphia, PA, USA, 1977.

17. ASTM E-662, Standard test method for specific optical density of smoke generated by solid materials. American Society for Testing and Materials, Philadelphia, PA, USA, 1979.
18. Clark, F.B. and Lyons, J.W., "The alcoholysis of polyphosphoric acid", *J. Amer. Chem. Soc.*, Vol. 88, 1966, pp 4401-4405.