Fire Performance of Aging Cable Compounds

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Cables and Cable Materials

Fire performance for different cable types

Cable Class:	Fire Performance:	Used in:
Mineral Insulation (copper sheathed)	Fire survival & circuit integrity up to the melting point of copper Negligible fire hazard	Critical circuits such as emergency lighting or fire alarms
Limited circuit integrity Low fire, zero halogen	Limited fire survival Flame retardant Low smoke and acid gas emission	As above but circuit integrity maintained for shorter time. Reduced hazard from cable combustion
Limited circuit integrity, reduced hazard (halogen containing)	Limited fire survival Flame retardant Low smoke & acid Gas emission	As above, but increased hazard from smoke and acid gas emission
Low fire hazard, low smoke, zero halogen	Flame retardant, low smoke & acid gas emission	For areas where smoke and acid gas evolution pose a hazard to personnel or equipment.
Low emission PVC based (or chlorinated polymer)	Flame retardant grades possible Reduced smoke and/or acid gas Reduced flame propagation possible	Where reduced levels of smoke and corrosive gas are needed compared to ordinary PVC or chlorinated polymers
PVC or chlorinated polymer	Flame retardant	Where flame retardance is desirable
Fluoropolymer based	Inherently flame retardant	High temperature or aggressive environments
Non-flame retarded	Readily combustible	Where fire performance requirements are low

Moore, G.F. (1997) Electrical Cables Handbook 3rd Ed, Blackwell Publishing

Ignition Properties of Polymers

Polymer	Flash ignition temp (°C)	Self ignition temp (°C)	LOI (%O_2)	Heat of combustion (MJ/kg)
Polyethylene	341 – 357	349	18	46
Polypropylene	320	350	18	46
Ethylene-propylene rubber (EPR)	--	--	18	--
Chlorosulphonated polyethylene (CSP)	--	--	27	28
Polychloroprene (PCP)	--	--	26 – 40	24
Silicone Rubber	490	550	26 – 39	--
Polyvinyl chloride (PVC) plasticized	391	454	47	19
Polystyrene	350	490	18	40
Nylon 66	421	424	20	33
Polytetrafluorethylene (PTFE)	560	580	95	Endothermic
Polyurethane	310	416	16.5	28
Wood	220 – 264	260 – 416	22 – 25	18.5
Wool	200	590	24 – 25	20
Cotton	230 – 266	254 – 400	18 – 27	16.7

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Common Flame Retardants used in Electrical Cables

- ***Mineral Based:***
  - Antimony trioxide (Sb_2O_3)
  - Ammonium Octamolybdate (AOM) – $(NH_4)_8Mo_8O_{26}$ (Smoke suppressant)
  - Magnesium Hydroxide – MgOH
  - Magnesium Oxide – MgO
  - Aluminum trihydroxide – $Al(OH)_3$
  - Zinc Oxide – ZnO
  - Zinc Borate Hydrate - $2ZnO \cdot 3B_2O_3 \cdot 3.5H_2O$
- ***Halogen Containing:***
  - Decabromo(diphenylene) oxide
  - Ethylenebis-tetrabromo-phthalimide
  - Chlorinated hydrocarbon waxes
  - Brominated and chlorinated hydrocarbon waxes
  - Dechlorane Plus ($C_{18}H_{12}Cl_{12}$)

What determines flame behavior?

- Ease of ignition
- Resistance to propagation (flame spread)
- Heat of combustion (heat release)
- Smoke emission
- Toxic gas evolution
- Corrosive gas evolution

All polymers will burn under fire conditions with few surviving temperatures above 500 °C

Aged Flammability Performance

Aged Flammability Performance

- "…thermal aging did cause changes in the thermal damageability of the cables tested; however, the changes observed are not considered risk significant…"
  - 1991, Nowlan S.P., The Fire Performance of Aged Electrical Cables, SAND91-0963C

- "…oxygen index flammability measurements showed moderately increased flammability for certain aged EPR samples…(containing various commercial halogenated hydrocarbon fire retardant additives together with SB_2O_3)…, but showed significantly decreased flammability for aged CSPE …(with and without added SB_2O_3)… which was correlated with the loss of other volatile components from the formulation…"
  - 1983, Clough R.L., Journal of Polymer Science, Polymer Chemistry Edition, Vol. 21, 767-780

“The Fire Performance of Aged Electrical Cables”

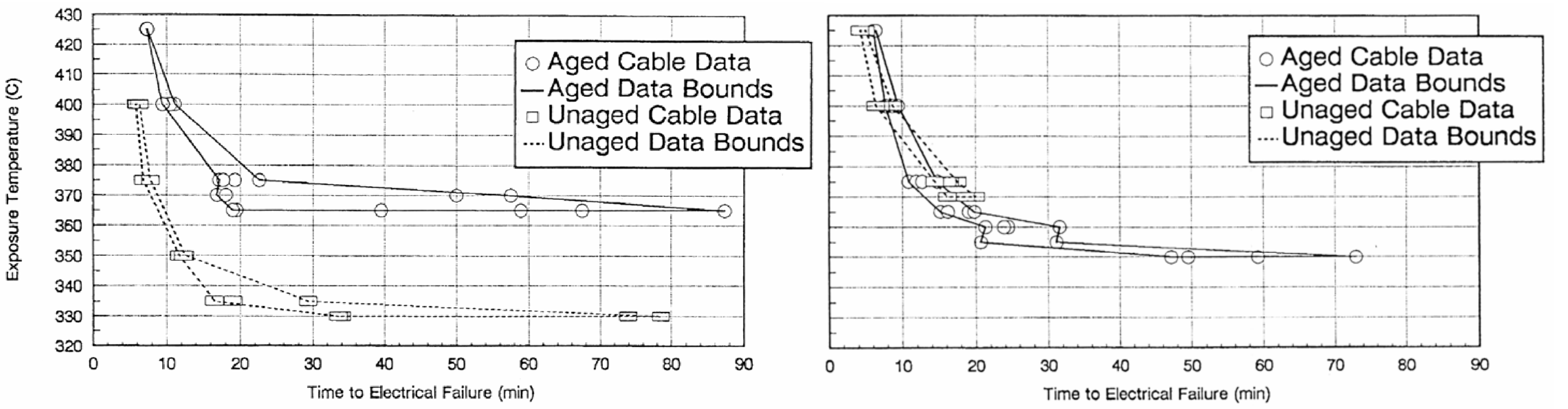
- Two types of cables tested
  - Neoprene jacketed, cross linked polyethylene (XPE) insulated, three conductor, 12AWG, 600V light power or control cable
    - Firewall III, Rockbestos
  - Ethylene-propylene rubber (EPR) insulated, chlorosulfonated polyethylene (CSPE or Hypalon) jacketed two conductor, 16AWG, plus shield and drain, 600V instrumentation cable
    - Bostrad 7E, BIEW Cable Systems Inc
- Flammability reduced due to aging.

Table 3: Summary of Cable Aging Flammability Test Results

Test Sample:	Aging Condition:	Peak Heat Release Rate (kW)	Peak Fire Growth Rate (kW/s)	Total Heat Release (MJ)	Peak Near-Fire Temp. (°C)
BIW Bostrad 7E:					
	Unaged Condition	588	21	302	954
	Aged Condition	329	3	139	872
Rockbestos Firewall III:					
	Unaged Condition	985	11	540	975
	Aged Condition	752	8	429	750

S.P. Nowlen “The Fire Performance of Aged Electrical Cables”, SAND91-0963C, Sandia National Laboratories 1991

“The Fire Performance of Aged Electrical Cables”



(a) Rockbestos Firewall III Neoprene/XPE Cables.

(b) BIW Bostrad 7E EPR/Hypalon Cables.

SCETCH test (Severe Combined Environments Test Chamber

Energized to 208VAC, 3 phase: 208 VAC conductor/conductor & 120 VAC conductor/ground; no current loading

Exposure to constant elevated temperature

Failure based on time at which a 5 A fuse failed for any individual conductor

“Aging Effects on Fire-Retardant Additives in Polymers”

TABLE VIII
Oxygen Index Data on Samples of Chlorosulfonated Polyethylene Aged at 110°C

Formulation	Aging time (months)	Oxygen index
HYP-I	Unaged	35
	4	46
	8	46
HYP-II	Unaged	39
	4	43
	8	50

For CSPE “..Oxygen index measurements indicated very large changes ……… less flammable after aging…..most likely results from loss of low molecular weight organic components…”

TABLE VI
Oxygen Index Data on Aged Samples of Fire-Retarded EPR Formulation EPR-V

Aging conditions	Oxygen index
Unaged	28.0
12 months at 100°C	27.0
8 months at 110°C	26.5
4 months at 120°C	26.0

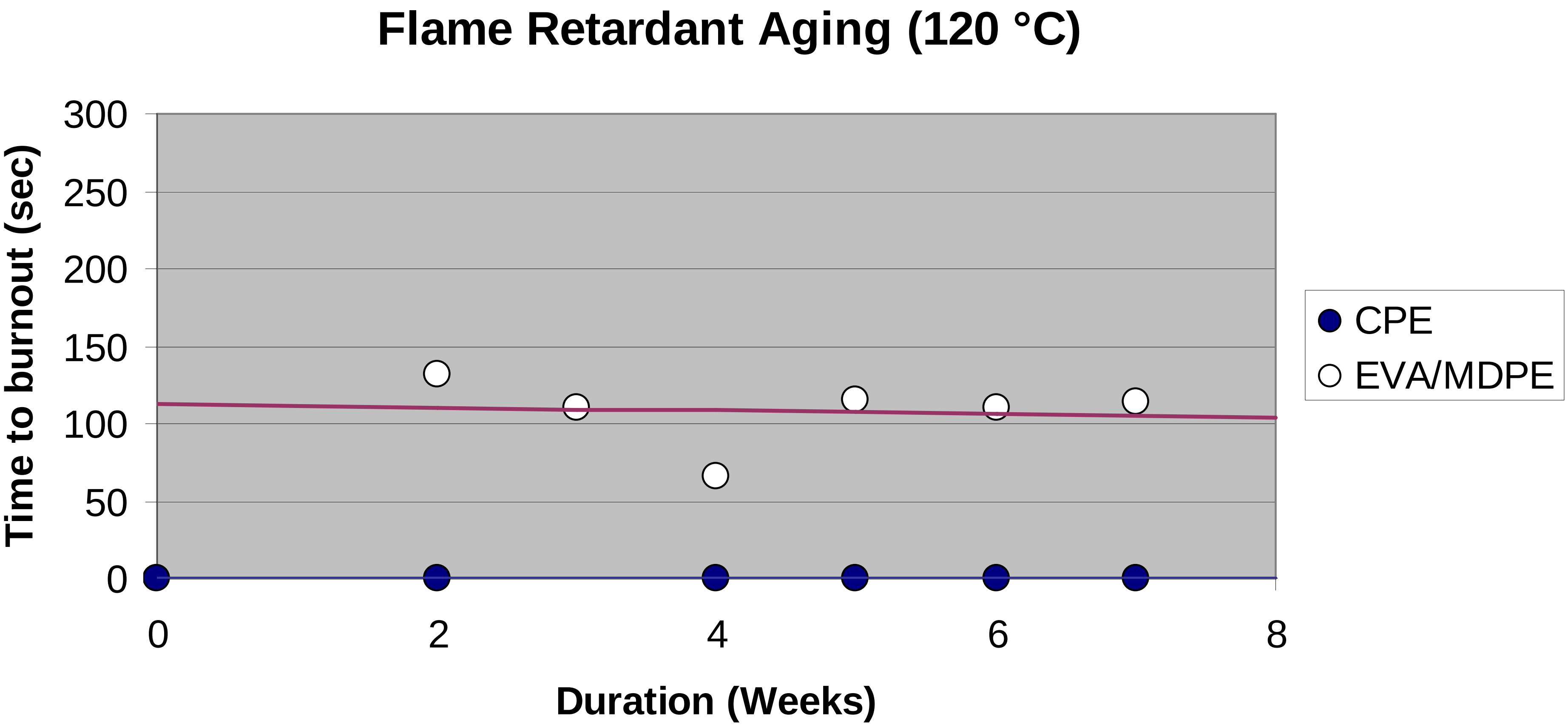
For EPR “..Changes in oxygen index are not large; the aged samples exhibit moderately increased flammability…”

R.L. Clough, Aging Effects on Fire-Retardant Additives in Polymers, J of Polymer Science: Polyer Chemistry Edition, Vol. 21, 767-780 (1983)

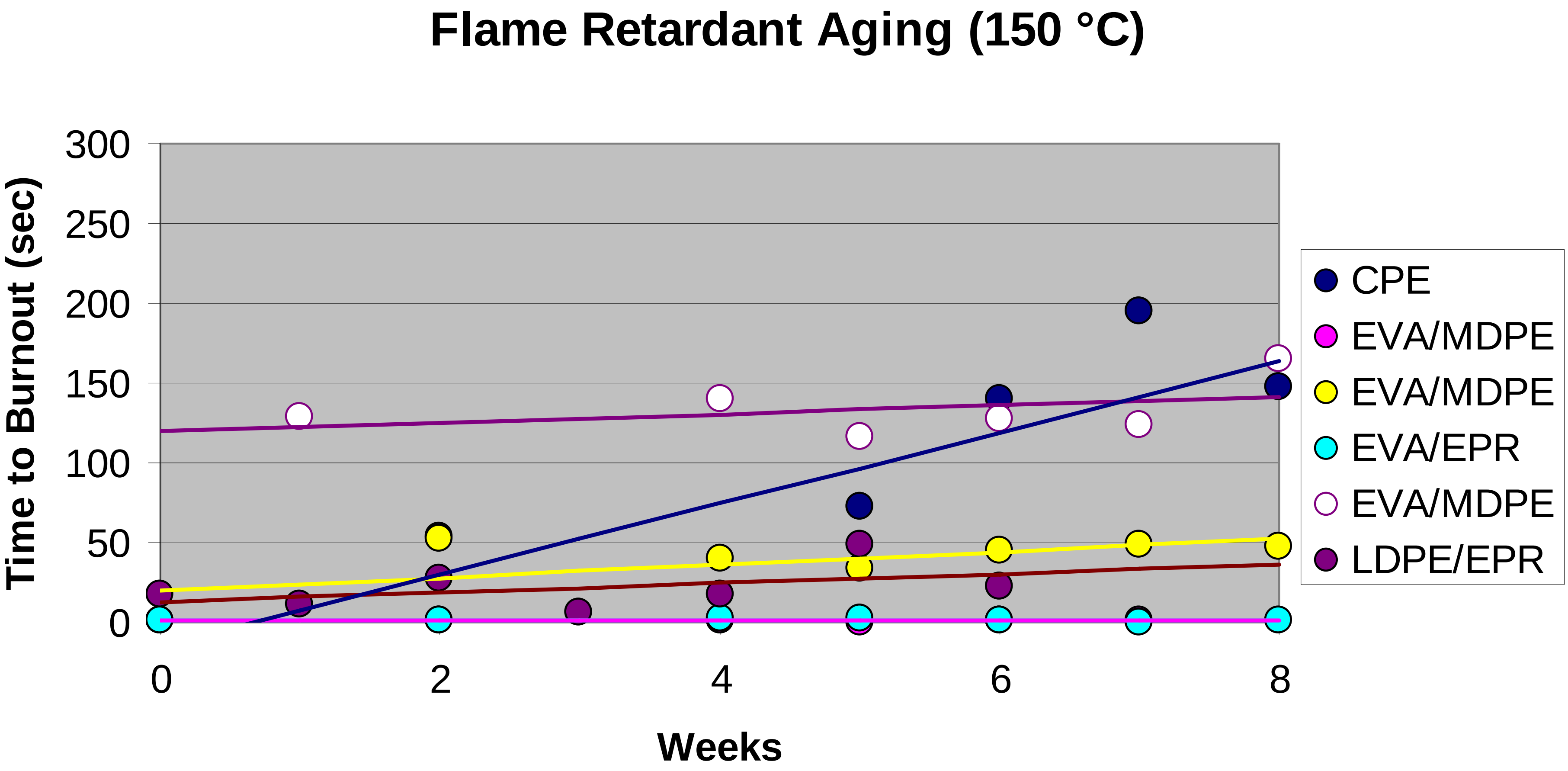
The Fire Performance of Aged Electrical Cables

- Comparing fire performance of flame retardant compounds
  - Accelerated heat aging
    - temperatures ranging from 120-175 °C for up to 8 weeks
  - Typical 600V control and instrumentation cables
  - Resins:
    - polyethylene, chlorinated polyethylene (CPE), and EPR
  - The flame retardants were typical industrial packages
    - Including antimony trioxide (Sb_2O_3), halogenated compounds, & hydrated minerals.
  - Flame test:
    - Apply a flame for 30 seconds
    - Measure the time required for the flame to extinguish
    - Compare burnout time of aged sample & unaged samples

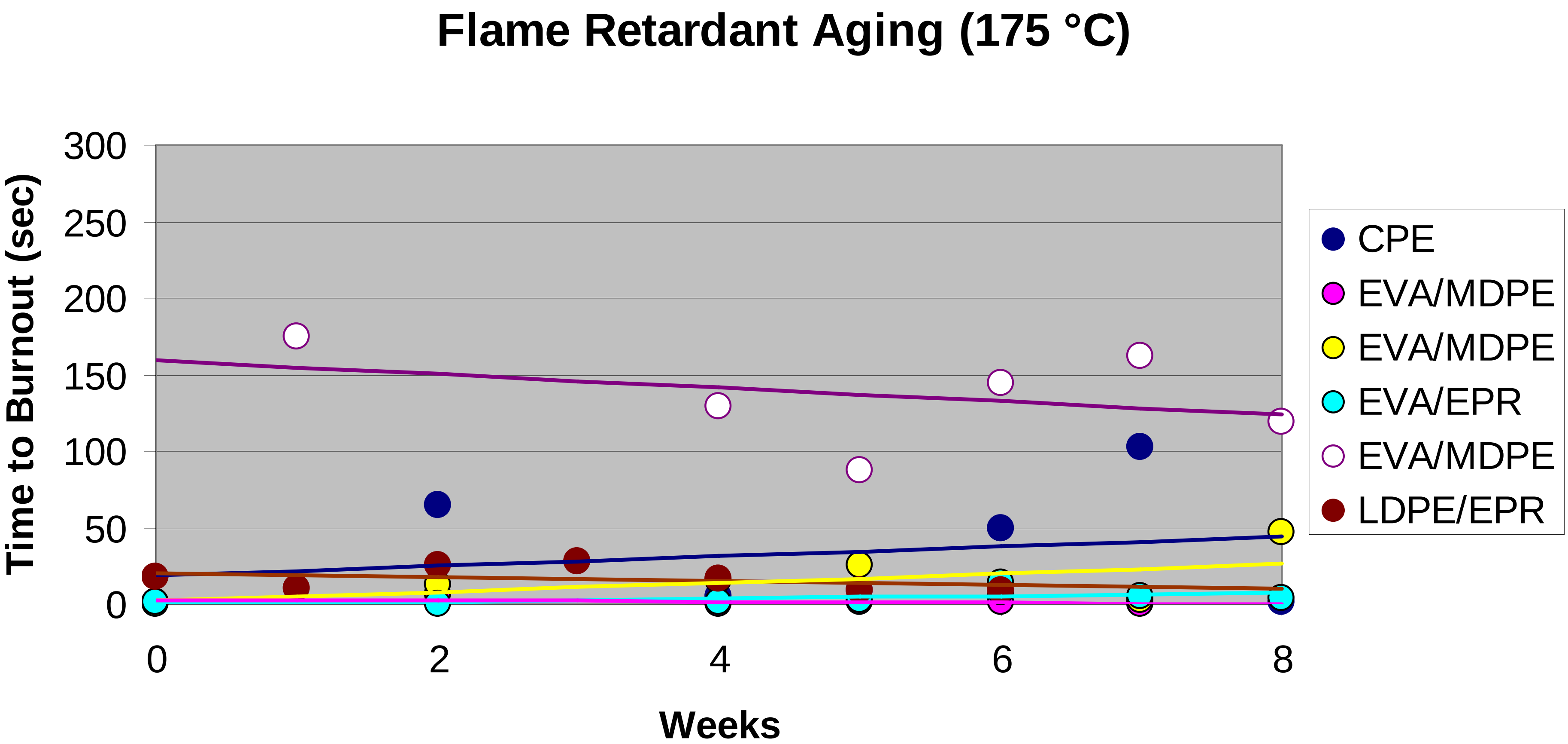
The Fire Performance of Aged Electrical Cables



The Fire Performance of Aged Electrical Cables



The Fire Performance of Aged Electrical Cables



The Fire Performance of Aged Electrical Cables

- Preliminary results
  - Minimal aging effects on flame retardant properties
  - Samples tested at 120 °C showed little change, with the CPE sample actually showing a minimal increase in flame retardancy
  - The samples tested at 150 °C and 175 °C showed slight aging effects
  - Further testing is required to ascertain the efficacy and age resistance of these flame retardant packages, but initial testing does not show a large correlation between aging and flame retardant ability

Environmental Legislation

Europe Risk Assessment Program

- EU risk assessment program
  - Evaluates risk for high production volume chemicals
    - Assess mammalian and environmental toxicology
    - Environmental fate and releases
      - Water, soil, air through out product life cycle
      - Exposure levels
  - The most comprehensive of current global health & environmental assessment programs
  - Looked at:
    - Pentabromodiphenyl ether
      - Unfavorable
      - Prohibited in EU effective Aug 15, 2004
    - Octabromodipheny ether
      - Some risk
      - Prohibited in EU effective Aug 15, 2004
    - Decabromodiphenyl ether
      - No identified risks to human health or environment
      - Environmental monitoring program now underway to be reviewed in 6 to 10 years
    - Also under review:
      - Tetrabromobisphenol-A
      - Hexabromocyclododecane
      - Tris(2-chloroethyl) phosphate
      - Tris(2-chloropropyl) phosphate
      - Tris(2-chloro-1-(chloromethyl)ethyl) phosphate
      - 2,2-bis(chloromethyl)trimethylene bis (bis(2-chloroethyl)phosphate)
      - SB_2O_3

Europe RoHS initiative

- RoHS Directive
  - **R**estriction of use **o**f **H**azardous **S**ubstances
  - Directive is a legally binding document, for EU member nations.
    - Establishes regulations at the EU level, which flow to each member nation.
    - Each government must pass its own laws, patterned after the RoHS directive, and do so by the deadline.
  - Directive issued January 27, 2003 by the European Commission (EC)
    - European Union (EU) member nations must enact local legislation by August 13, 2004, which will implement the RoHS directive as regulatory requirements before the activation date of July 1, 2006.

Substance	**Max conc** **% by wt of homogenoeus material**
Cadmium (CD)	0.01
Hexavalent Chromium (CR VI)	0.1
Lead (Pb)	0.1
Mercury (Hg)	0.1
Polybrominate biphenyls (PBB)	0.1
Polybrominated diphenyl ethers (PBDE)	0.1

Based on the favorable results of the European risk assessment, commercial available Deca-BDE was exempted Oct 2006

Europe RoHS initiative

- Covered product categories:
  - Large household appliances
  - Small household appliances
  - IT and telecommunications equipment
  - Consumer equipment
  - Lighting equipment
  - Electrical and electronic tools (except large-scale stationary and industrial tools)
  - Toys, leisure and sports equipment
  - Automatic dispensers

- Medical devices and measuring and control instruments, are exempt from RoHS requirements until which time the EU Commission includes them
  - Estimated to occur in 2008 or 2009

- Electrical and Electronic Equipment (EEE) is defined as devices which are dependent on electric current or electromagnetic fields to work properly, including that equipment used to generate, transfer, or measure such currents or fields.
  - Definition of EEE for RoHS is limited to those devices operating on a maximum 1000 Volts AC or 1500 Volts DC.

Europe RoHS initiative

- If you sell electrical or electronic equipment to any member country of the European Union, or if you sell parts or materials to companies that then sell their products on the EU market, your products are likely to be covered by RoHS

- Even if your products aren't destined for the EU market, you still may be affected
  - Laws such as SB 20 and SB 50 in California are already taking effect in the US, and many more are in the works here and in countries such as China, Japan, and Canada
  - Component availability and reliability are issues, since the "old" products containing restricted substances will become harder to find and more expensive to buy
    - Example, even though medical devices are now exempt from RoHS, manufacturers may have problems getting printed circuit boards with the tried and true tin-lead solder.

- Suppliers outside EU cannot be prosecuted
  - Therefore EU producers are responsible
    - Producers will need to take "reasonable steps" to ensure their products compliance

- Products place on market are presumed to comply with RoHS directive
  - Enforced by market surveillance
    - Hand held XFR
    - Detector swabs
  - If challenged producers will need to demonstrate that they have taken "reasonable steps" to comply
    - Reasonable steps never defined

Europe REACH Inititiative

- Registration Evaluation Authorization of Chemicals
- Will affect all chemicals, including flame retardants
- Will require industry to register all existing and future new substances with a new European Chemicals Agency
- Expected to be finalized early in 2007 and put into force mid 2007
  - There will be a 18 month period for pre-registration of substances
- Process will replace RoHS
- All chemicals will be required to undergo one or more steps in the REACH process
  - Registration
  - Evaluation
  - Authorization
  - Restriction
- Most likely only compounds classified as persistent, bioaccumulative & toxic or very persistent, very bioaccumulative or category 1 & 2 carcinogens, mutagens & reproductive toxins will be required to undergo authorization

European WEEE Initiative

- **W**aste **E**lectrical & **E**lectronic **E**quipment **D**irective
- Sets requirements for the collection, treatment, recycling and recovery of WEEE.
- Financing of most of the activities is the responsibility of the producers with retailers and distributors also having take-back and other responsibilities.
- Was to begin August 2005
  - EU member states encountering major difficulties in meeting deadline and have delayed implementation
- Impact on flame retardants:
  - Selective treatment of plastics containing BFRs
    - Requirement fullfilled when WEEE plastics treated together with other wastes. As is the case with energy recovery processes currently practiced in Europe

U.S. Environmental Regulations

- SNUR
  - Significant New Use Rule
  - EPA proposed 2004
  - Requires EPA review and approval prior to import of penta-BDE and octa-BDE into the U.S.
- Eight states have enacted legislation prohibiting the use of Penta and Octa -BDE products
  - California
  - Hawaii
  - Illinois
  - Maryland
  - Maine
  - Michigan
  - New York
  - Oregon
- There are no restrictions on Deca-BDE within the U.S.

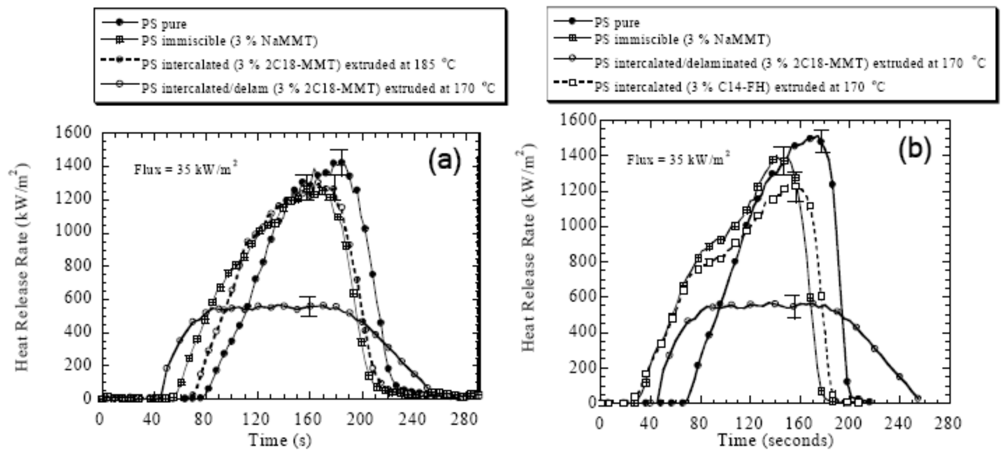
Environmental Regulations Worldwide

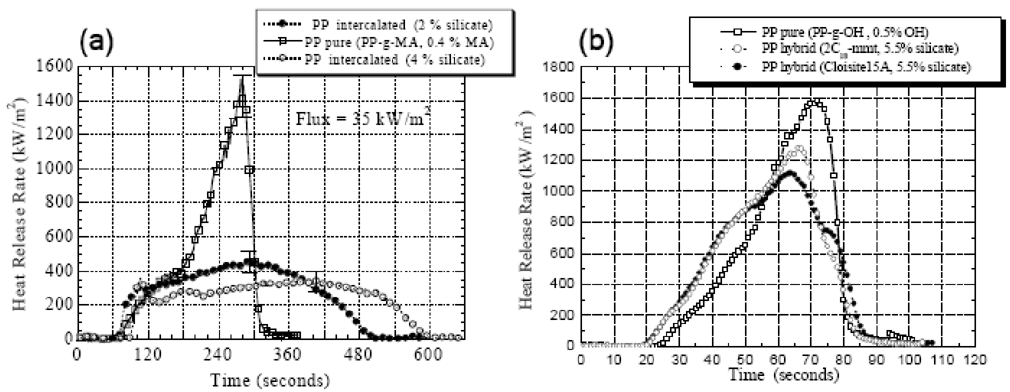
- **Japan**
  - 1998 The Ministry of Trade and Industry proposed recycling legislation to reduce the use of lead in electronics
  - Targeted reduction of lead use was by half by 2000 and two-thirds by 2005
  - Japanese Home Electronics Recycling Law called for OEM's in Japan to be prepared to collect and recycle four major products by April 1, 2001.

- **China**
  - The electronics industry is one of the fastest growing industries in China.
  - The Ministry of Information Industry (MII) has drafted legislation similar to WEEE/RoHS to restrict hazardous substances due to concern over the rate of waste accumulation contributed by domestic consumption and shipment into China containing hazardous scrap for "reclamation" by other countries.

- **Korea**
  - In an effort to maintain their current electronics industry, Korea adopted a voluntary program to phase out hazardous chemicals banned in the RoHS Directive. An overwhelming majority of companies in Korea are voluntarily eliminating these chemicals from their production.

New Technology
Polymer Clay Nanocomposites





J.W. Gilman, C.L. Jackson, A.B. Morgan, R. Harris, E. Manias, E.P. Giannelis, M. Wuthenow, D. Hilton, and S.H. Philips, 2000. Flammability properties of polymer layered-silicate nanocomposites. polypropylene, and polystyrene nanocomposites. Chem. Mater., 12:1866—1873. [11] J.W. Gilman, T. Kashiwagi,

Conclusions

- Accelerated thermal aging data on cable compounds appears to show a small to negligible affect.
  - Both increases and decreases in flammability with time have been reported