FR Technology & Fire Test Requirements For The E&E Industry

Alexander B. Morgan, Ph.D.
Applied Combustion and Energy Group
Energy Technology and Materials Division
University of Dayton Research Institute
937-229-3079
alexander.morgan@udri.udayton.edu

Outline

- FR Technology Overview
  - What is a Flame Retardant and How Do They Work?
  - Flame Retardant Classes & Chemistries
- Flammability Tests for Electrical & Electronic Applications
  - Testing Overview – What Is Measured and Why
  - Test Methods – Regulatory and Non-Regulatory
- Conclusions

FR Technology Overview

What is a Flame Retardant?

- A Flame Retardant (FR) is a molecule/polymer (inorganic or organic) found to be useful for inhibiting flame growth by one of three mechanisms.

- A Flame retardant is a chemical used for a specific application, much like a drug is a molecule used to treat disease, a pigment is a molecule used to give paint a color, or a surfactant is a molecule to use as a soap.
  - FR is used to put out a fire either passively (guard against fire) or actively (extinguishing agent).
  - Some FR additives have multiple chemical applications – again application based upon chemical structure and how it interacts with fire.
    - Ex: $Mg(OH)_2$. In powder form can be used in antacids or can be used as flame retardant filler in wire and cable jackets.
      - But the product used for wire and cable is not the same product you eat nor can the two be used interchangeably.

General Flame Retardant Approaches for Polymers

I- Gas Phase Flame Retardants (ex. Halogen, Phosphorus)
- Reduce heat in gas phase from combustion by scavenging reactive free radicals, resulting in incomplete combustion.
- Can be very effective at low loadings.
- Inherent Drawbacks: Increase in CO and smoke.

II- Endothermic Flame Retardants (ex. Metal Hydroxides, Carbonates)
- Function in Gas Phase and Condensed Phase by releasing non-flammable gases (H_2O, CO_2) which dilutes the fuel and cools the polymer.
- Tend to be very cheap in cost.
- Inherent Drawback: High loadings degrade mechanical properties.

III- Char Forming Flame Retardants (ex. Intumescents, Nanocomposites)
- Operates in Condensed Phase by preventing fuel release and providing thermal insulation for underlying polymer.
- Very robust method at providing fire safety.
- Not universally acceptable for all polymer systems, can be expensive.

Gas Phase Flame Retardants

- Gas phase flame retardants include halogenated organics, organophosphorus materials, and a few other select molecules.

- Gas phase flame retardants interact chemically with the free-radical process that is polymer combustion.
  - Prevent the formation of certain molecules which are exothermic in formation. (ex. H· + ·OH → HOH)
  - Halogen (F, Cl, Br, I) or Phosphorus (P-O or P) are the most common vapor phase radical scavenger/inhibitors for flame chemistry.

- The effectiveness of a gas phase flame retardant is determined by its effective "Release Temperature" and the polymer degradation pathway of the material being flame retarded.

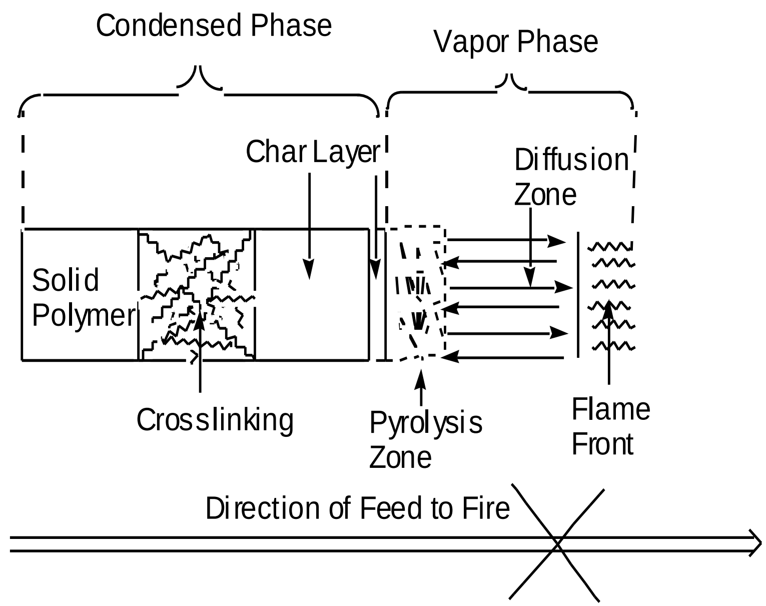
Endothermic Flame Retardants

- Endothermic flame retardants include metal hydroxides such as $Al(OH)_3$ (aka $Al_2O_3 \cdot 3H_2O$), $Mg(OH)_2$, and some mineral carbonates (ex. Hydromagnesite)

- Endothermic flame retardants work by releasing a non-flammable gas via an endothermic decomposition event.
  - Water or CO_2 is released into the vapor phase, diluting the total amount of fuel available for combustion.
  - Endothermic decomposition cools the condensed phase, slowing down degradation, or, taking away heat that would lead to fuel release.

- The effectiveness of a endothermic flame retardant is determined by its effective "Release Temperature" and the polymer degradation pathway of the material being flame retarded.

Char Forming Flame Retardants



(Martin, D. C.; Spilman, G. E.; Markoski, L. J.; Jiang, T.; Pingel, E. *Society of Plastics Engineers, Inc.: Technical Papers* **1996**, *42*, 3008.)

- With the use of high char-forming, crosslinking, and pre-ceramic materials, we can potentially:

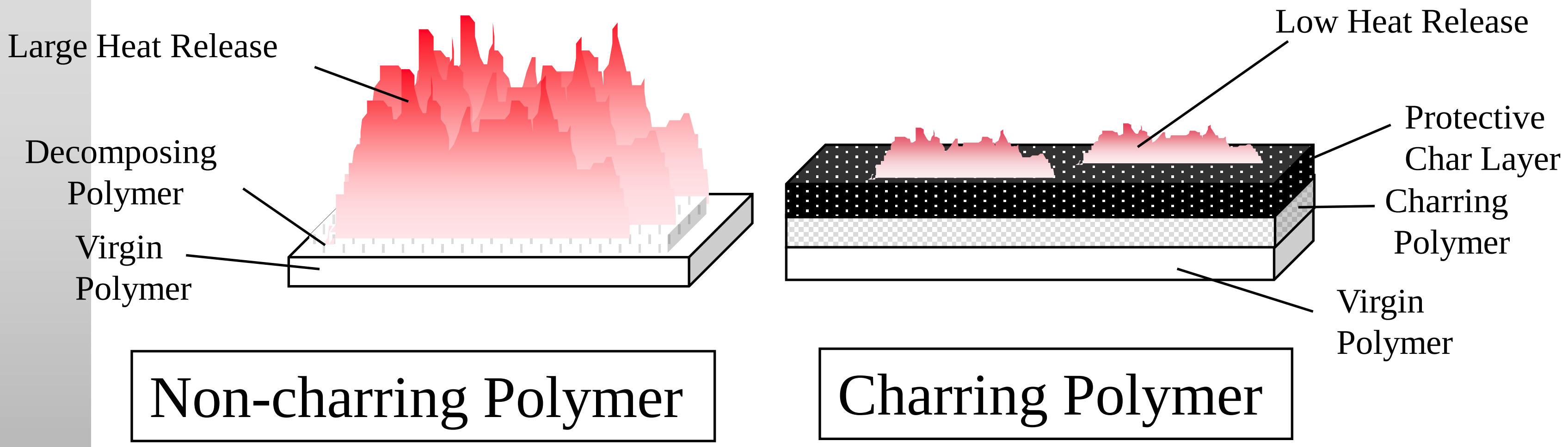
  (1) Prevent fuel molecules from reaching the flame front.

  (2) Prevent further depolymerization of the plastic.
- Char formation must activate before peak decomposition temperature so it has time to set up and provide protection.

Slide courtesy of J. Gilman, NIST

Fire Retarded Polymers by Enhanced Char Formation

- Increased char yield
- Increased rate of char formation
- Lower density char



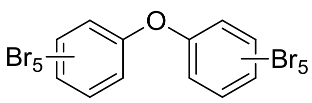
Specific Classes of Flame Retardants

Halogenated Flame Retardants

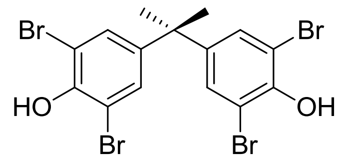
- Halogenated FR additives cover a wide range of chemical structures.
  - Aromatic additives often used for higher release temperature, higher % loading of halogen per molecule.
  - Aliphatic additives used for lower release temperatures, or to induce polymer depolymerization. Not used as often.
  - Brominated FR is the most common. Chlorinated FR is used, but not as often.
  - Fluorine and Iodine tend not to be as effective for FR polymer additive use.
    - Fluorinated compounds inherently non-flammable (Teflon, Halon)

- Halogenated FR additives often include synergists so that they can be more effective at lower loadings.
  - Antimony oxide the most common synergist.
  - Sometimes the synergist will be incorporated directly into the FR structure (ex – phosphorus – halogen)

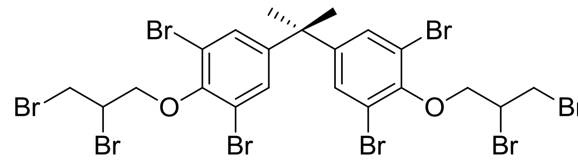
Uses of Common Brominated FR Additives



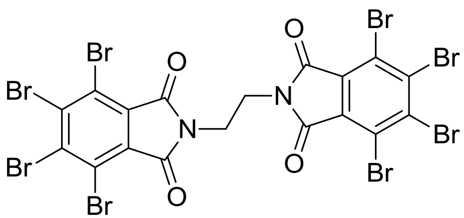
Decabromodiphenyl ether



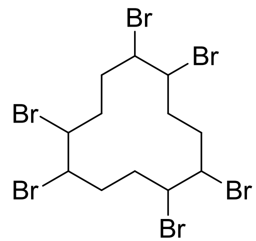
Tetrabromo bisphenol A



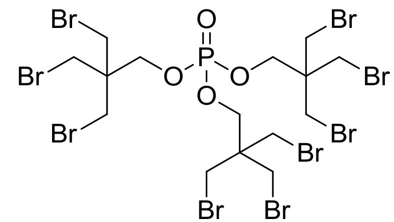
Bis(2,3-dibromopropyl ether) of Tetrabromo bisphenol A



1,2-ethylene bis(tetrabromophthalimide)



Hexabromocyclododecane



Tris(tribromoneopentyl) phosphate

- Decabromodiphenyl ether, 1,2-ethylene bis(tetrabromophthalimide):
  - Electronic cases, wire and cable jackets.
- Tetrabromobisphenol A:
  - Epoxy Circuit Boards (copolymerized – reactive FR)
- Hexabromocyclododecane:
  - Thermoplastic foams, textiles
- Bis(2,3-dibromopropyl ether)… / Tris(tribromo…)phosphate:
  - Polyethylene/polypropylene
- Many other additive systems available, including polymeric and oligomeric species for more specific applications.

Halogenated Flame Retardants

- Halogenated FR additive benefits:
  - Very effective at lowering flammability in a wide range of polymers.
  - Provide good fire performance even after repeated recycling of polymer + FR resin.

- Halogenated FR additive drawbacks:
  - Always generate more smoke and carbon monoxide during burning.
  - Can be overwhelmed in high heat flux fires (little to no FR effectiveness).
  - Under regulatory scrutiny due to perceived environmental problems.

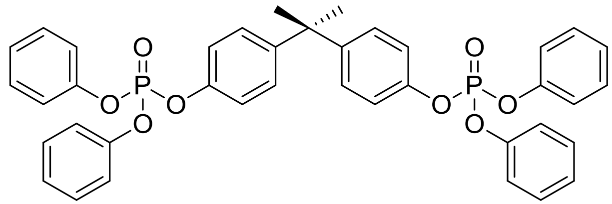
- Overall an old technology (since 1930s) but proven to work.

UDRI UNIVERSITY of DAYTON RESEARCH INSTITUTE

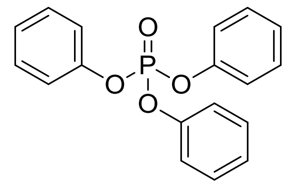
Phosphorus Flame Retardants

- Phosphorus FR additives cover a wide range of chemical structures and can be both gas and condensed phase FR additives.
  - Aromatic/aliphatic structures are used for polymer compatibility purposes.
  - Oligomers are used for cost effectiveness or ease of manufacture.
  - Inorganic phosphorus FR is used when more condensed phase effects are desired.
  - Encapsulated elemental red phosphorus can be a very effective flame retardant for some systems.
- Phosphorus FR additives do not typically need synergists, but sometimes they are more effective when combined with other types of flame retardants or elements.
  - Halogenated FR (Phosphorus-halogen vapor phase synergy)
  - Nitrogen compounds (Phosphorus-nitrogen condensed phase synergy)

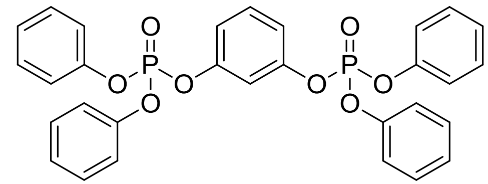
Common Phosphorus FR Structures and Chemistry



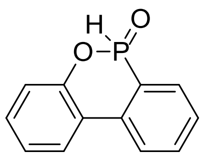
Bisphenol A Diphosphate



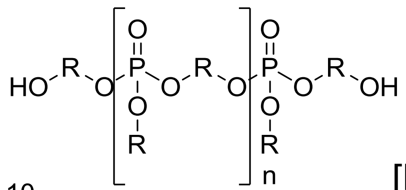
Triphenylphosphate



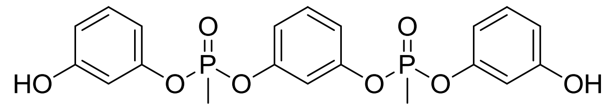
Resorcinol Diphosphate



9,10-dihydro-9-oxa-10-phosphaphenanthrene-10-oxide (DOPO)



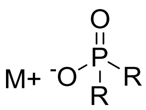
Phosphate Polyol



Poly methylphenyl phosphinate (PMP)

$[NH_4PO_4]_n$

Ammonium Polyphosphate



Phosphinate Salts
M = Al, Zn
R = Alkyl

- Phosphorus FR Uses:
  - Phosphates/phosphinates: Electronic plastics
  - DOPO / PMP: Reactive FR for circuit boards
  - Ammonium polyphosphate: Fire wall barriers / intumescent paints
  - Phosphate polyol: Reactive FR for polyurethane foam (new)
- Organic groups (phenyls, “R”) can vary widely.
  - Methyl groups substituted ortho to oxygen on phenyl rings for better hydrolytic stability.

Phosphorus Based FR

- Common non-halogenated flame retardant.
  - Has been in use since the 1950s. Fairly mature technology and chemistry.
  - Used in a wide range of applications – electronics, textiles, building and construction, structural composites, consumer goods
- Phosphorus FR additive benefits:
  - Can be both vapor phase and condensed phase flame retardants.
  - Can be very effective at lowering heat release rate at low loadings of additive.
- Phosphorus FR additive drawbacks:
  - Tend to generate more smoke and carbon monoxide during burning.
  - Not effective in all polymers.
  - Also under some regulatory scrutiny.

Mineral Filler Flame Retardants

- Mineral filler flame retardants cover hydroxides and carbonates.
  - Hydroxides (Al, Mg)
    - $Al(OH)_3$ releases water at a low release temperature (180-200 °C)
    - $Mg(OH)_2$ releases water at a higher release temperature (320-340 °C)
  - Carbonates (Ca, Mg)
    - Calcium carbonate often used as a bulk filler, and since it is non-flammable it dilutes the total amount of fuel to be consumed.
    - Magnesium carbonates used in a form called "hydromagnesite" which releases a combination of water and CO_2 at 350 °C.

- Mineral fillers do not typically use synergists, but sometimes they will be combined with other FR additives to provide a beneficial effect on polymer flammability.
  - Al, Mg hydroxides sometimes used to lower smoke output while providing FR performance.

Mineral Fillers

- Mineral Filler Types
  - Metal Hydroxides
    - Magnesium Hydroxide - $Mg(OH)_2$
    - Aluminum Hydroxide / Alumina Trihydrate (ATH) – $Al_2O_3 \cdot 3H_2O$
    - Boehemite (Aluminum hydroxy oxide – AlOOH)
    - Double Layered Hydroxides
  - Carbonates
    - Huntite / hydromagnesite blends
    - Calcium carbonate
  - Layered minerals
    - Talc / Kaolinite
- Materials can be coated or uncoated for better compatibility with the polymer matrix.

Mineral Filler Flame Retardants

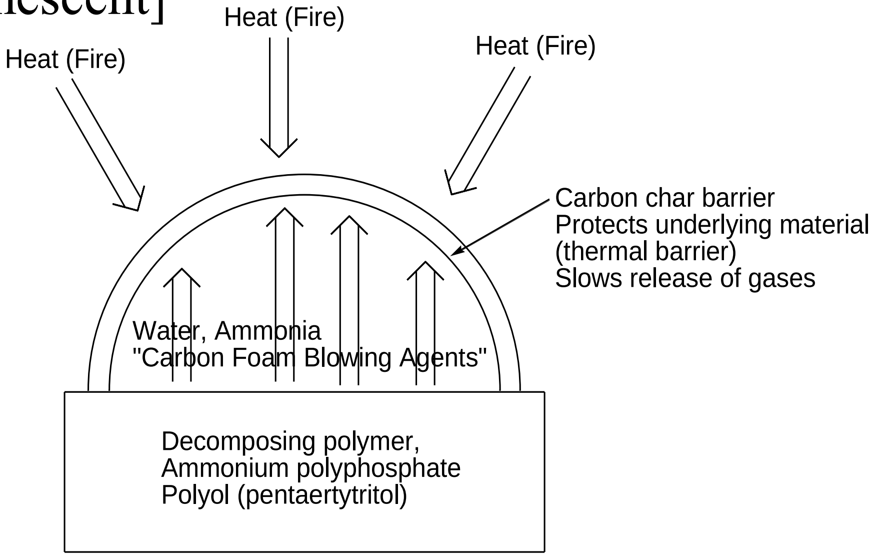
- Mineral Filler FR additive benefits:
  - Effective at lowering heat release rate and smoke release.
  - No environmental scrutiny – considered to be very “green” FR additives.

- Mineral Filler FR additive drawbacks:
  - Not as effective per wt% basis as other FR additives. Large loadings of material (50-80wt%) can be required to obtain FR performance in polyolefins.
  - High loadings often cause mechanical property problems which can lead to the use of polymer compatibilizers that offset some of the cost benefits of using a mineral filler in the first place.

- Depending upon what sources you believe, could be very old technology (1600s) or 20th century (1920s).

Intumescent Flame Retardants

- Intumescent FR additives are often mixtures of different additives that work together under fire conditions to form a protective barrier (carbon foam) at that "rises up in response to heat" [Intumescent]
  - Intumescent FR packages include:
    - Carbon source
      - Polymer or Polyol
    - Acid source
      - Ammonium Polyphosphate
    - Gas-blowing additive.
      - Melamine



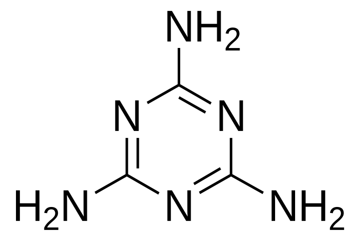
  - There are FR systems where more than one aspect of the intumescent package can be incorporated into the additive structure (additive is carbon/acid source and gas-blowing additive) .
  - Sometimes the polymer actively participates in the charring process by serving as the carbon source.

Intumescent Flame Retardants

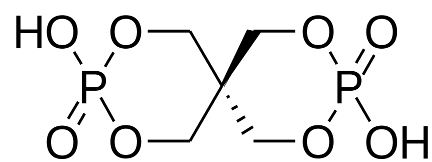
- Intumescent FR additive benefits:
  - Very robust fire safety and flame resistance performance.
  - One of the few systems that can use select polymer structures to actively participate in flammability reduction.
- Intumescent FR additive drawbacks:
  - Can have water pickup issues.
  - Can be expensive.
  - Can have low temperature limits that limit processing ranges.
- Intumescents are often used for applications requiring high levels of flame retardancy.
  - Building and construction, firewall/firedoor barriers, aerospace, military, wire & cable, mass transport, etc.

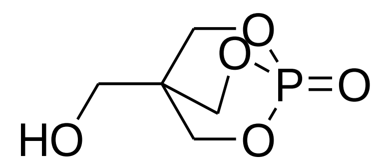
Other Intumescent Additives

- Melamine and derivatives
  - Co-blowing agent (NH_3 release)
  - Additional FR chemistry
    - Melamine phosphate or polyphosphate – replaces ammonium polyphosphate
    - Melamine borate – intumescent strengthening, glow (smolder) suppressant.



- Intumescent FR Molecules
  - Combine polyol, phosphate in same molecule
    - Various structures available





- Inorganic Additives
  - Used to strengthen char against thermal degradation
    - Clays
    - Zeolites
    - Silicones

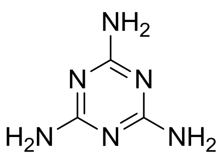
Inorganic Flame Retardants

- Inorganic Flame Retardants are a broad class of materials that mostly affect condensed phase phenomena.
  - Zinc Borate ($2ZnO \cdot 3B_2O_3 \cdot 3.5H_2O$)
    - Can release water, but mostly helps as a FR synergist for phosphorus and mineral FR.
    - Helps to lessen afterglow (smolder) conditions.
  - Silicone compounds
    - Can form protective silicon oxide barrier against fire.
      - Polycarbonate commercial product in Japan
      - CASICO (Calcium Silicon Carbonate) Wire and Cable system from Borealis
    - Often part of commercial proprietary systems – not something you buy and use alone.
- Inorganic FR additives are typically synergists for other FR additives, or they offset an undesirable property brought by the main FR.

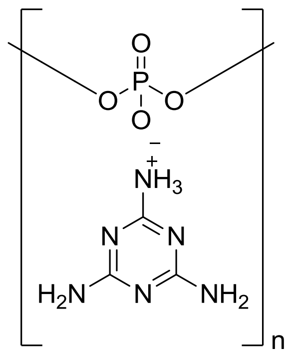
Inorganic Flame Retardants

- Inorganic FR additives are used for balance of property or synergist purposes.
  - Stannates are used to reduce smoke (especially in PVC).
  - Zinc Borate can be combined with many different FR additives, but only in low amounts. Higher loadings often brings FR antagonism.
  - Silicon compounds can reinforce intumescents, or provide FR performance directly to a polymer.
  - Charring salts (sulfonates) for polycarbonates change decomposition chemistry of polycarbonate to make it char and not drip during burning.
- Inorganic FR additive benefits:
  - Typically used in small amounts to offset an undesirable FR property.
  - Little or no environmental scrutiny.
- Inorganic FR additive drawbacks:
  - Not effective by themselves except in very specific systems – not a universal class of FR additives.
  - Tend to be expensive.
- Various specialty providers worldwide.

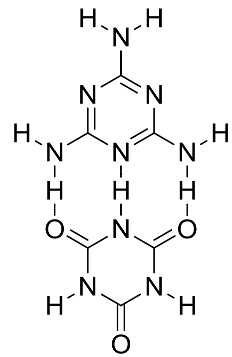
Nitrogen Based FR



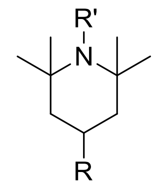
Melamine



Melamine Polyphosphate



Melamine Cyanurate



R = Alkyl, polymer
R' = H, oxyalkyl

Hindered Amine Light Stabilizer (HALS)

- Nitrogen based flame retardants almost solely based upon melamine.
  - Typically used in intumescent formulations, except:
    - Melamine Cyanurate – used for Nylons (helps them drip away from the flame)
    - Melamine – used for rigid polyurethane foam to lower flammability.
    - HALS and N-oxyalkyl HALS (NOR-HALS) used to provide V-2 for polypropylene.
      - Primary use – UV stabilizer, mechanism of FR not fully understood.

Nitrogen Based FR

- Nitrogen based FRs not widely used – either a niche FR or used as part of another system.
  - Intumescents
  - Char formation (Phosphorus – Nitrogen synergy)

- Advantages to Nitrogen Based FR
  - Melamine low cost material – brings some vapor phase activity to flame retardancy (NH_3).
  - Little environmental scrutiny / concern.

- Disadvantages to Nitrogen Based FR
  - Water pickup / absorption issues.
  - Not terribly effective outside their typically used polymer / FR applications.

Polymer Nanocomposites

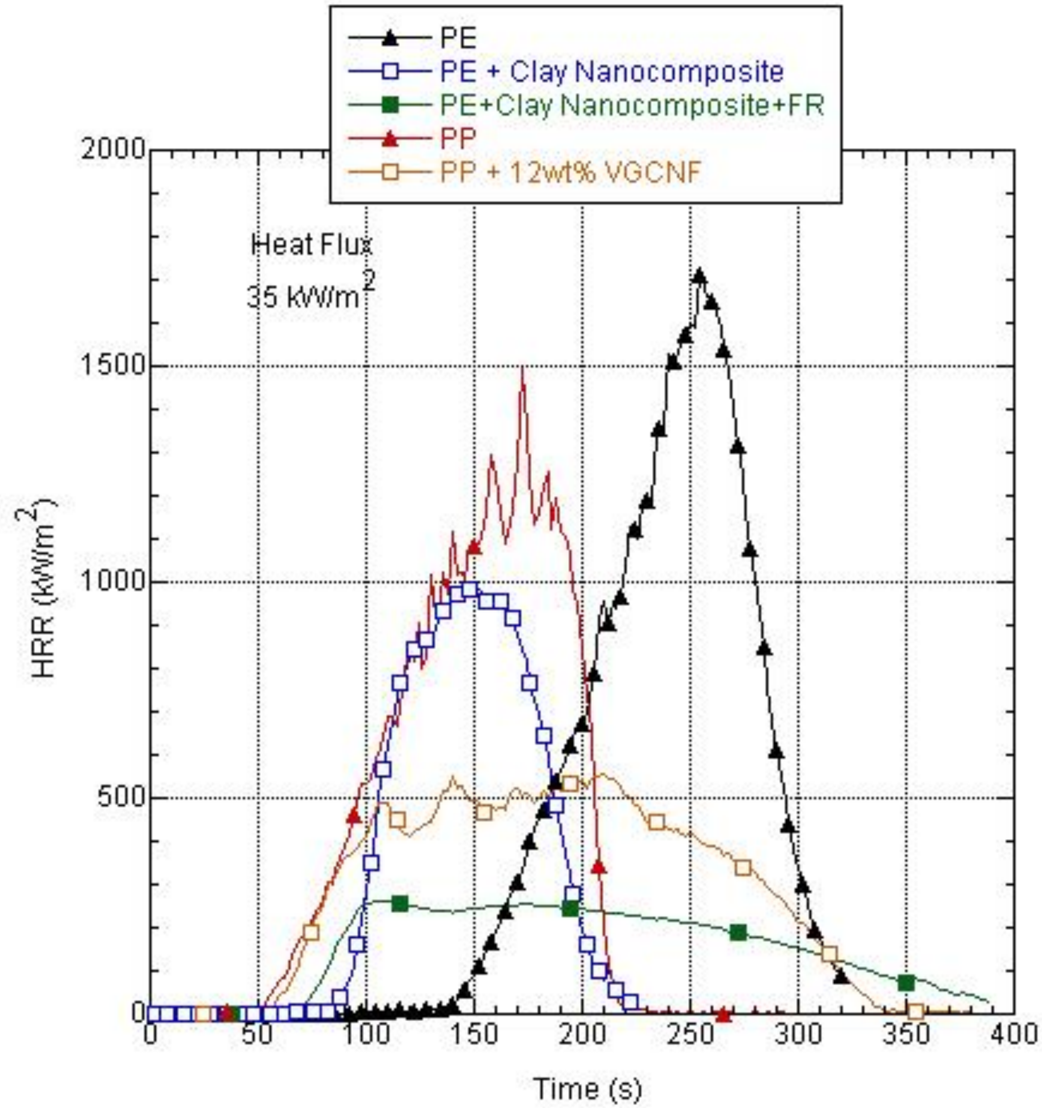
- Polymer nanocomposites are a new class of FR additives that work only in the condensed phase.
  - Use organically treated layered silicates (clays), carbon nanotubes/nanofibers, or other submicron particles at low loadings (1-10wt%).

- By themselves, polymer nanocomposites greatly lower the base flammability of a material, making it easier to flame retard the polymer containing a nanocomposite structure.
  - Are effective when combined with just about all types of FR additives.
  - Work best when combined with other FR additives.
  - In effect, nanocomposites are a class of *nearly* universal FR synergists.
    - Exceptions do exist of course.

- As polymer nanocomposites become commercial materials – they will also be flame retardant materials at the same time due to their inherent properties.

Polymer Nanocomposite Cone Calorimeter Data

- For PE + clay nanocomposite (5wt% inorganic), peak HRR is reduced, but Total HR remains unchanged.
- Polymer clay nanocomposites lower the mass loss rate, which in turn reduces the base flammability, but additional FR is needed to lower HRR further.
- PE + Clay + FR even better fire performance.
- Similar behavior seen for nanocomposites made with nanofibers and nanotubes



Flame Retardant Polymer Nanocomposites

- Polymer nanocomposite benefits:
  - Brings balance of mechanical and flammability properties to a system.
  - Very little additive needed (no great cost increase).
  - Tend to inhibit polymer dripping / flow under fire conditions.
  - Multifunctional performance (ex: electrical conductivity from carbon nanotubes)

- Polymer nanocomposite drawbacks:
  - Difficult to set up a polymer nanocomposite structure.
  - Design of the nanocomposite requires careful design and analysis, which can bring additional R&D cost to a product.
  - Lots of unknowns with nanocomposite technology (long-term aging, EH&S, etc.)
  - New technology (1990s – maybe not proven enough for conservative fire safety principles)

FR Additive Types Summary

- 3 Broad classes of FR Additives
  - Gas Phase
  - Endothermic
  - Char Forming/Condensed Phase
- 7 Classes of FR Additives
  - Halogenated (Gas Phase)
  - Phosphorus (Gas and Condensed Phase)
  - Mineral Fillers (Endothermic)
  - Intumescent (Char Forming/Condensed Phase)
  - Inorganic (Mostly Condensed Phase)
  - Nitrogen Based (Gas and Condensed Phase)
  - Polymer Nanocomposites (Condensed Phase)
- Choosing which FR additive and class to use involves understanding of polymer structure/degradation pathway and regulatory test.

Flammability Tests for Electrical & Electronic Applications

Regulatory Tests

- Regulatory tests developed by fire safety engineers to address fire risk scenarios.
  - A fire risk scenario is the chance of a fire occurring when a material is in a specific situation exposed to a specific open flame/ignition source/fire threat.
    - Example: Short circuit in a battery pack inside a laptop during battery charging.
  - The tests attempt to mimic the scenario of concern – not on chance of fire occurring, but assume fire will occur and measures how the material behave in response to that scenario.
  - Tests try to measure material response in repeatable, verifiable manner such that response is indication of favorable response to fire threat (pass) or would lead to loss of goods or life in the case of a negative response to fire threat (fail).

Regulatory Tests

- Regulatory pass fail tests are then used to qualify / certify goods under specific codes and standards
  - Codes and standards set by government, industry.
  - I'm not a codes and standards expert – See Marcelo Hirschler of GBH International for all your codes and standards questions.
- Regulatory tests are what one uses to develop flame retardant materials.
  - Design to pass the test because universal fire safety is very expensive to obtain and not always practical.
  - Passing regulatory tests is usually the path to customer satisfaction and codes/standards compliance.
    - However….
      - Tests tend to be reactive to fire problems, not proactive.
      - May solve yesterday's problems rather than today meaning the legacy test no longer reflects real world fire scenarios.
- But regulatory tests are what you have – so how does one proceed?

UDRI UNIVERSITY of DAYTON RESEARCH INSTITUTE

Flame Retardant Molecule Design / Use Criteria

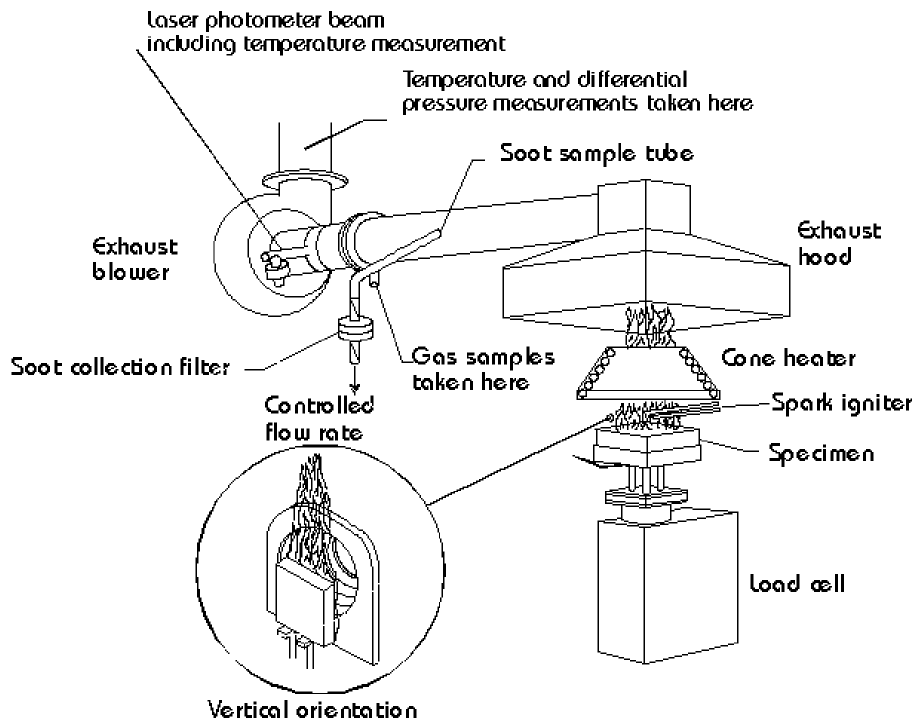
- Current flame retardant polymer solutions are tailored to the regulatory test the polymer must pass to be sold. So the molecules are designed and applied to solve the following problems:
  - Ignition Resistance
  - Flame Spread
  - Heat Output
  - Structural Integrity Under Fire and Heat
  - Smoke/Toxic Gas Output
  - Combinations of one or more of the above
- What works for one test may not (and often does not) work for another test!!!!
- The Flame Retardant Chemist will design to the test, not universal flame retardancy.
  - The Chemist can only design to the criteria given (fire, cost, performance, lifetime, etc.). It is impossible to design for the the unforeseen criteria that may occur 10-20 years later.
- "If we knew what we were doing, it wouldn't be called research, would it?" - Albert Einstein

Regulatory Pass/Fail Tests

- Simple way to measure flame retardancy – try the formulation in the final regulatory test.
  - Pro: Save time – test is needed at the end anyway.
  - Con: Regulatory tests often do not include useful scientific information, just passes or fails, and no data showing *why* the material passed or failed.
  - If this is one's only option, then one should at least watch the test performed to see *how* the material passed or failed the test.
- Preferred way to measure flame retardancy – scientific tests.
  - Pro: More useful data and understanding of how a material performs. Better chance of success when scaling up to final regulatory test.
  - Con: Correlating the data from the scientific test can be difficult.
  - While this route is preferred, some time may be needed up front correlating existing materials that pass the final regulatory test to the scientific test.
- Two key scientific tests to choose from: Cone Calorimeter and Pyrolysis Combustion Flow Calorimeter.

Cone Calorimeter – ASTM E1354

- Quantitative Fire Test, accepted by fire scientists, fire safety engineers, regulatory groups.
- Measures flammability by oxygen consumption calorimetery.
- Materials exposed to heat fluxes equal to particular fire scenarios.
- Mass loss rates, smoke output, CO/CO_2 release rates are measured.
- Flammability measured by heat release rate (HRR) and Total heat release (Total HR)
- Higher HRR, Total HR = greater fire risk, base polymer flammability



Picture courtesy of www.doctorfire.com

Cone Calorimeter Data Interpretation

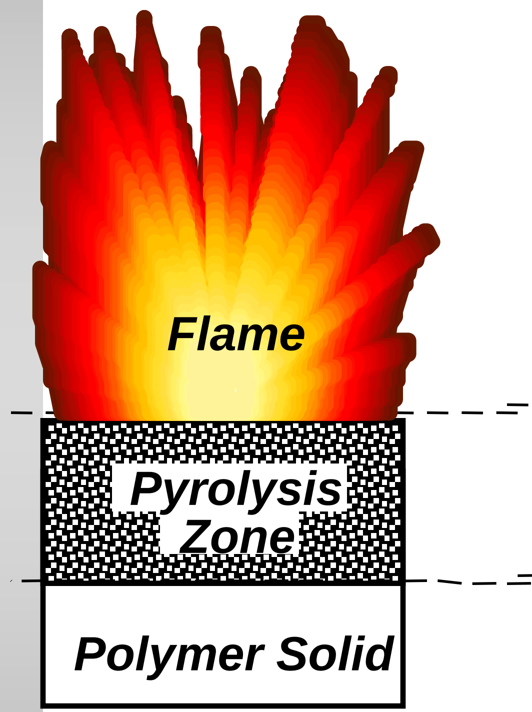
- Along with HRR and Total HR, other parameters such as time to ignition (T_{ig}), peak heat release rate (Peak HRR) and time to Peak HRR can be important factors to understand.
- Correlations between cone calorimeter data and final scale regulatory tests have been established for some materials (mostly in flame spread tests)
  - EU Single Burning Item
  - W&C Burn tests (See EU FIPEC results)
- Peak HRR, Time to Peak HRR and Fire Growth Rate index (FIGRA) have been some of the most useful parameters in looking at cone calorimeter data.
  - Peak HRR = Highest heat output (peak of flammability) in fire – greatest chance of flame propagation to remaining polymeric material, or to other objects nearby.
  - Time to Peak HRR = Time to the highest heat output (how fast the fire peaks in intensity)
  - FIGRA = Peak HRR/Time to Peak HRR [kW/m^2 per second] = rate of fire growth.

Pyrolysis Combustion Flow Calorimeter (PCFC)

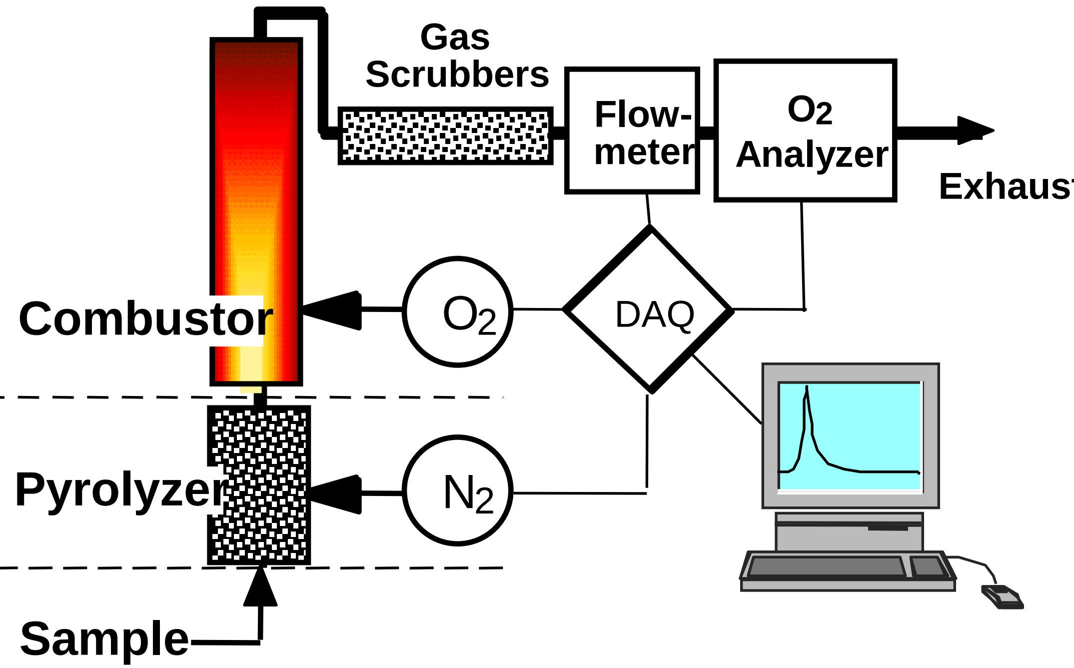
- The Pyrolysis Combustion Flow Calorimeter is a recently developed oxygen consumption calorimeter instrument.
  - Developed by Rich Lyon/Rich Walters of the Federal Aviation Administration.
  - Currently being sold as a commercial instrument by Fire Testing Technology or GovMark.
  - Small scale flammability test – 5 to 50mg of material.

- Since PCFC is as new technique, the correlation to other tests has only begun to be established.
  - Well established for cone calorimeter average HRR for pure materials.
  - Reasonable correlation with UL-94 for pure materials.
  - The effects of polymer FR additives, or polymer blends on PCFC measurements have not been established.
  - Correlation to other techniques has also not been established.

FAA Microscale Heat Release Rate Test: Pyrolysis-Combustion Flow Calorimeter (PCFC)

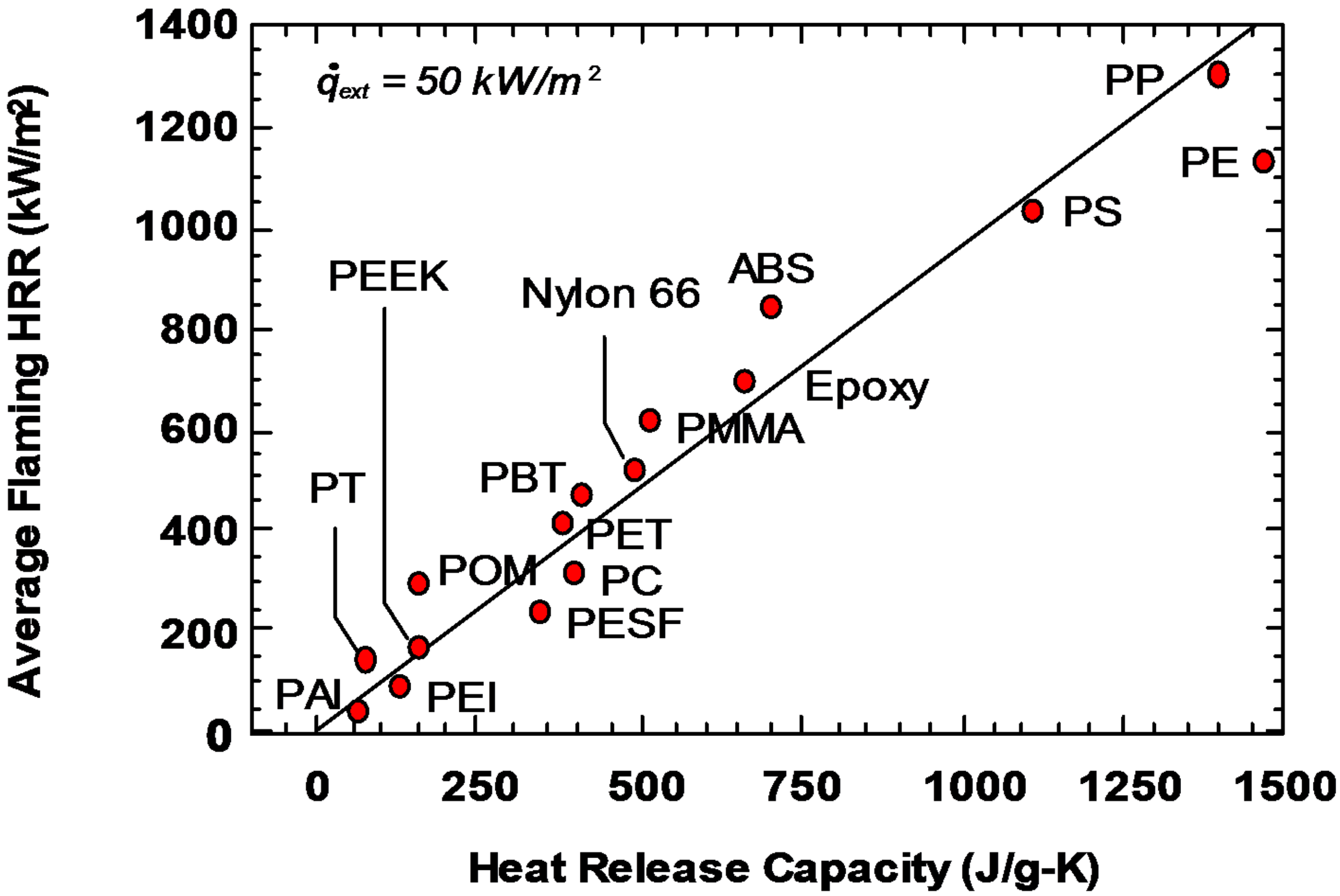


Burning Polymer

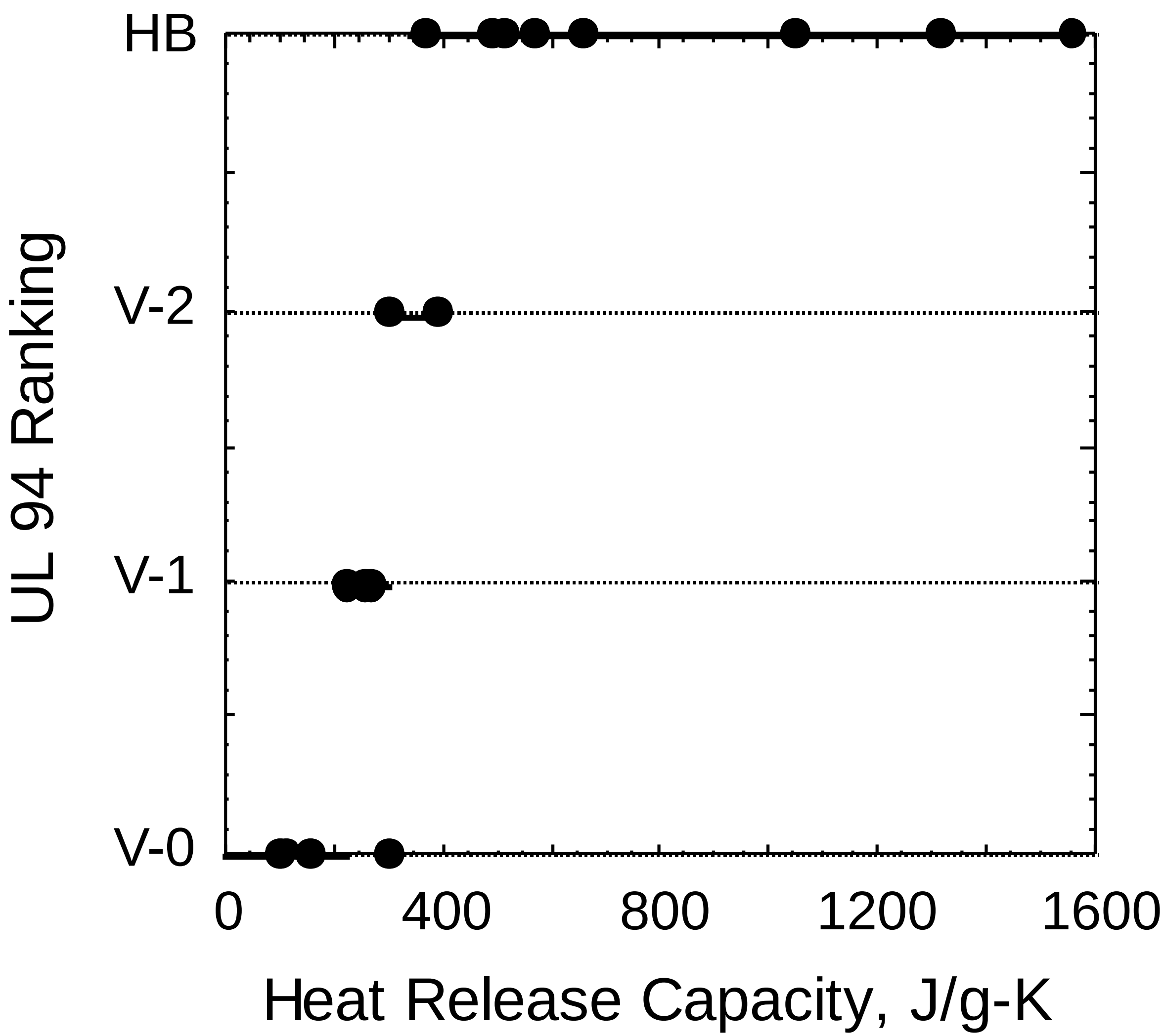


Pyrolysis Combustion
Flow Calorimeter (PCFC)

Cone-PCFC Correlation



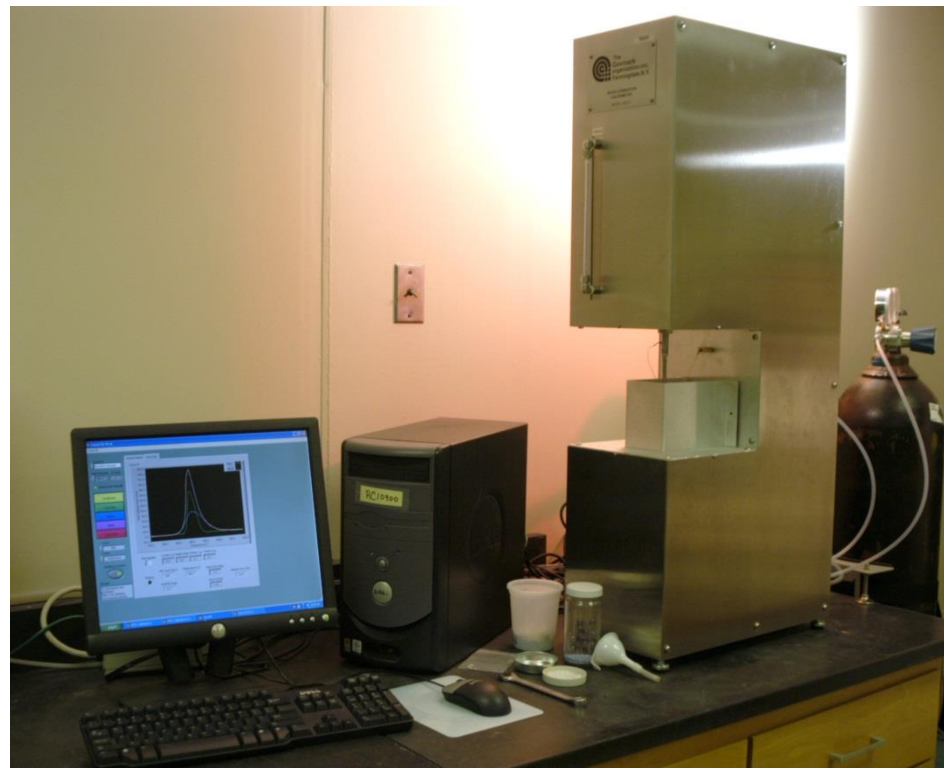
UL-94-PCFC Correlation



UDRI UNIVERSITY of DAYTON RESEARCH INSTITUTE

UDRI Fire Testing Capabilities

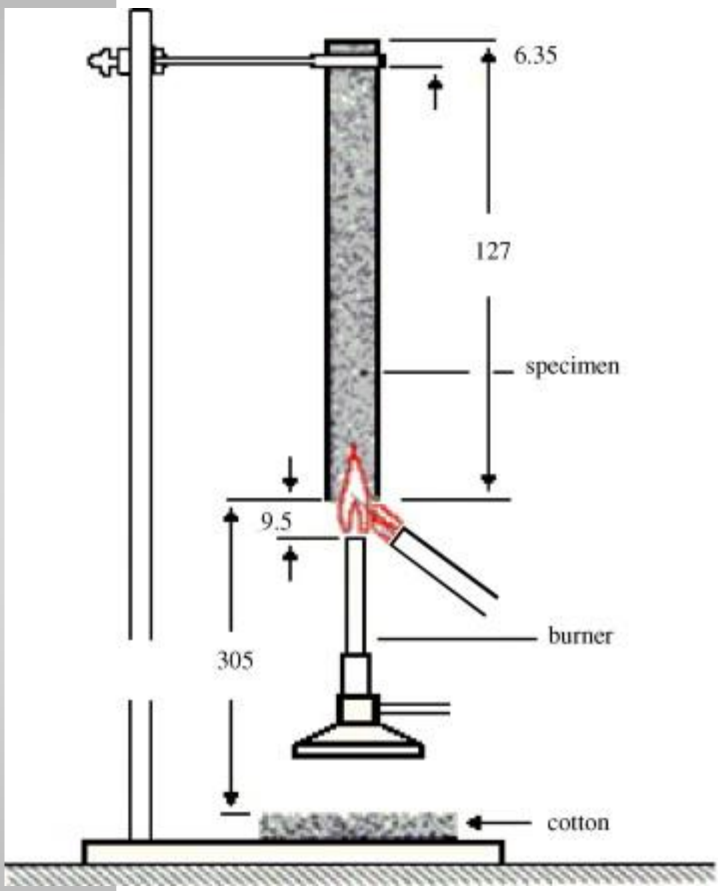
- Cone calorimeter (left)
- PCFC (right)

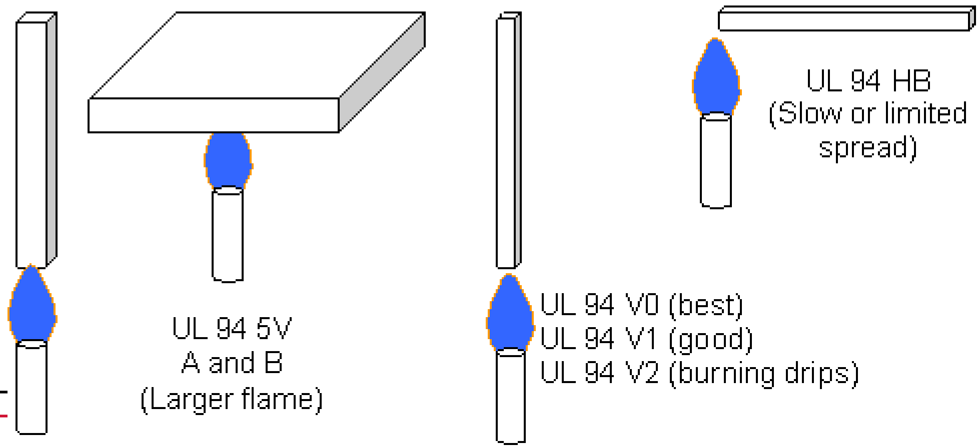


UL-94

- UL-94: Test for Flammability of Plastic Materials for Parts in Devices and Applications
  - Includes ASTM D635 (UL-94 HB), ASTM D3801 (UL-94 V), ASTM D4804 (UL-94 VTM), ASTM D5048 (UL-94 5V), ASTM D4986 (UL-94 HBF)
  - Open flame test which is part thickness, geometry, and orientation dependent.
- Test method chosen depends upon how plastic component will be used.
  - UL-94 V most common for electronics.
    - UL-94 5V used when electronic enclosures are of large size, or, fire performance needs to be more robust.
  - UL-94 Rating (V-2, V-1, V-0, HB, 5VA, 5VB) selection governed by application.
    - See UL for details on what version is relevant to your product.

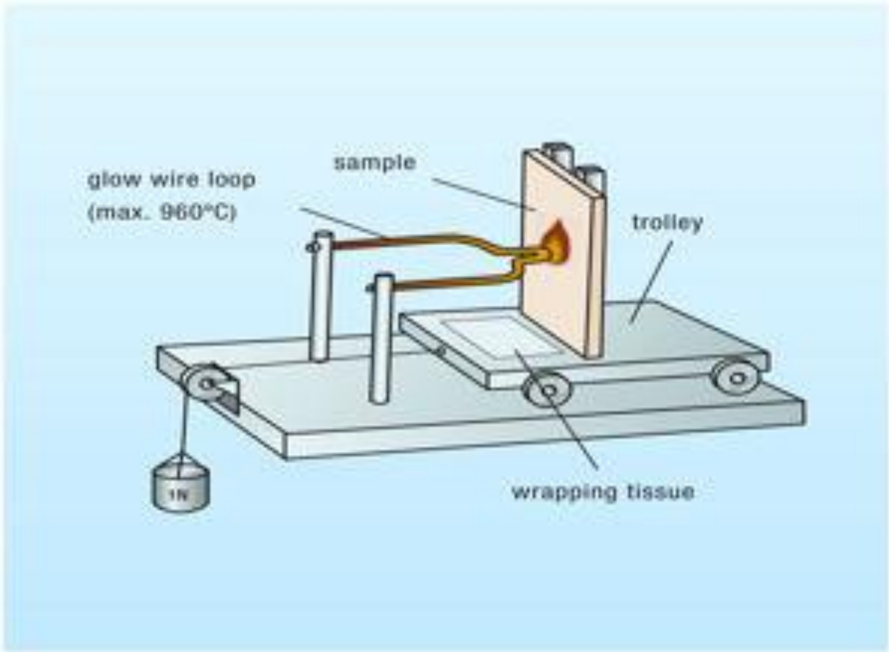
UL-94


6.35
127
specimen
9.5
burner
305
cotton


UL 94 HB
(Slow or limited spread)
UL 94 5V
A and B
(Larger flame)
UL 94 V0 (best)
UL 94 V1 (good)
UL 94 V2 (burning drips)

Glow Wire Test

- ASTM D6194: “Standard Test Method for Glow-Wire Ignition of Materials”
  - IEC 60695-2-10, UL746A
- Test looks at if materials ignite when exposed to a glowing wire heat source (of set temperature).
- Mimics a short circuit wire event.
- Ratings determined by temperatures the plastic resists ignition.



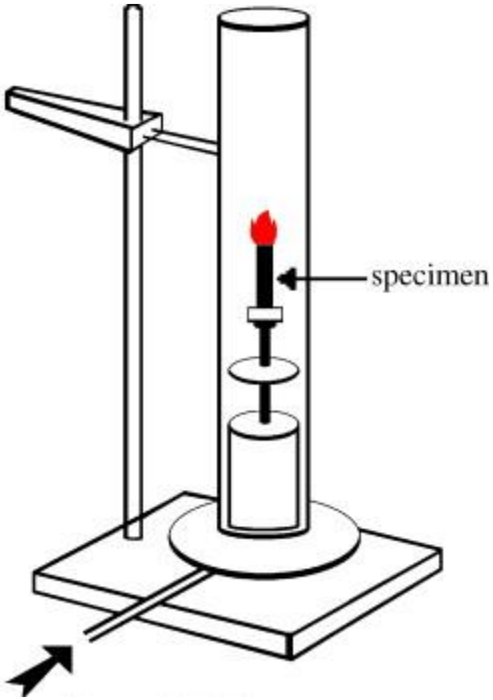
Wire & Cable Flame Spread Tests

- Covers a wide range of ASTM, ISO, IEC, and UL tests.
  - Test methods vary sample orientation (horizontal, vertical), construction (single wire, bundle, wire insulation), installation (plenums, risers) and fire source (open flame, underventilated, well ventilated).
  - Smoke and corrosive / toxic gas release may also be measured.
  - Very relevant to a wide range of E&E products.
    - Discussing the wide range of tests would be another seminar…

- Bottom line: pay close attention to which test you are being asked to meet.
  - Tests can look similar, but be different enough that it is not uncommon for one material to pass a test well, but fail another catastrophically.
    - Horizontal vs. vertical
    - Cable thickness, construction, installation differences
    - Cable composition for smoke and gas release

Limiting Oxygen Index

- ASTM D2863 "Standard Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (Oxygen Index)"
  - ISO 4892-1,2
- Useful test for quality control (quick way to check product consistency for flame retardant loading / flame retardant response).
- Test can give artificially high numbers if material excessively drips and flows during burning.
- Test does not correlate to any real world fire scenario
  - Use with caution for proving fire safe performance.



N2/O2 mixture input here

Conclusions

FR and Test Needs for E&E

- Several different choices of flame retardants available for E&E applications.
  - Three broad classes (vapor phase, endothermic, condensed phase)
  - Seven broad chemistries (halogen, phosphorus, mineral filler, intumescent, inorganic, nitrogen, nanocomposites)

- Flame retardants are selected based upon:
  - Polymer chemistry and fire physics
  - Regulatory test / flame retardant response need
    - Flame spread, ignition resistance, smoke/gas release, etc.

- Attention to polymer chemistry, regulatory test needs, commercial requirements, and environmental needs essential to successful E&E flame retardant material development.

Future Requirements for FR E&E

- Regulatory Drivers:
  - Environmental issues key driver for new FR for E&E
  - Recyclability of metals / rare earth oxides
  - Low to no environmental impact of FR resin
    - Can FR resin be recycled or used for waste-to-energy recovery?

- New Fire Risk Scenarios:
  - Battery fires (but may be solved with Lithium Air / ceramic batteries…)
  - Wall mounted televisions – is UL-94 V still relevant?
  - Tablets vs. Laptops vs. Smart Phones
  - Smoke / Gas Release from Wire and Cable

- Educated Guesses at this time – hard to predict what the future will bring.

Acknowledgements

- The American Taxpayer (Fire Grant 60NANB12D167)

- Flame Retardant Manufacturers
  - Albemarle
  - Amfine
  - Clariant
  - Great Lakes Solutions
  - ICL
  - Rio Tinto Borax

- PINFA

Questions?