



26th Annual Conference on Recent Advances in Flame Retardancy of Polymeric Materials

Chairman: Charles Wilkie
Marquette University

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Main Conference
May 18-20, 2015

Sheraton Stamford Hotel
Stamford, CT USA

Featuring presentations from outstanding scientists from around the world on
topics covering the entire spectrum of flame retardancy

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26th Annual Conference on Recent Advances in Flame Retardancy of Polymeric Materials

**May 18-20, 2015
Sheraton Stamford Hotel**

The complete technical and commercial development meeting on flame retardancy

Presentations at the conference will:

- **Create a forum for introducing new technological achievements and developments in the field of flame retardancy (FR)**
- **Offer an overview of the current state of science and technology in FR**
- **Review the applications and markets for FR products**
- **Present recent developments in local and global standardization in testing technology**
- **Discuss toxicity and environmental issues**
- **Provide a unique opportunity for newcomers to become acquainted with the FR field in all its aspects**
- **Discuss nanoparticles effects on flammability**
- **Address regulatory issues for flame retardancy**

Conference Benefits

- **Network with colleagues including expert speakers in Flame Retardancy**
- **Discover the latest technological advances**
- **Learn about leading commercial applications**
- **Hear the latest regulatory, environmental, and testing findings**



Intensive Short Course

Selection, Evaluation and Commercial Applications of Flame Retardant Polymers

Sunday, May 17, 2015, 8:30 – 5:00

Course Director: Charles Wilkie, Marquette University

Course Instructors

Matthew Blais: Fire Technology Department, Southwest Texas Research Institute (SwRI)

Sergei Levchik: Product Development Manager, ICL-IP America

Kelvin Shen: Consultant Rio Tinto Minerals

A Certificate of Participation will be awarded to attendees



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26th Annual Conference on Recent Advances in Flame Retardancy of Polymeric Materials

Featuring presentations from outstanding scientists from around the world on topics covering the entire spectrum of flame retardancy

Sessions on Commercial Products; Instrumentation: Phosphorus-based Flame Retardants; Foams and Fabrics; Nanocomposites: Flame Retardants for some Specific Polymers and Some Specific Flame Retardants

Conference Program

Sunday, May 17

2:00 – 4:00 and 6:00 – 7:00 Preregistration

6:00 – 7:30 Opening Reception

Monday, May 18

7:00 - 8:00 – BREAKFAST

8:00 Introduction to the Meeting – Charles Wilkie



Session 1: Commercial Products

Chairperson: Antenneh Worku

8:15

Comparative Burn of Flat Panel Televisions from United States, Mexican and Brazilian Markets

Dr. Matthew S. Blais

Fire Technology Department, Southwest Research Institute, San Antonio, TX 78238. blais@swri.org.

A comparative burn rate study was performed on televisions from US, Mexican and Brazilian markets using progressively increasing ignition source size on the back casing of like-model televisions. Chemical composition analysis of the television casings was performed prior to burning. Oxygen consumption calorimetry measured the heat release rate over the duration of the test. Emissions of bromo and chloro-dioxins were measured via an EPA Method 23a sampling train and high-resolution mass spectrometry. Other combustion products were monitored via Fourier Transform Infra-red Spectroscopy and EPA method TO-15. Significant differences were detected for the burning behavior and emissions between like-model televisions sold in the different markets which is directly associated with the presence of fire retardants.

8:45

Fire Hazards of Lithium Ion Batteries

Richard N. Walters, Richard E. Lyon, Sean Crowley and James G. Quintiere*

Federal Aviation Administration, William J. Hughes Technical Center, Fire Safety Branch ANG-E21, Atlantic City International Airport, NJ 08405. richard.e.lyon@faa.gov.

**Department of Fire Protection Engineering, University of Maryland, College Park.*

The high energy density of lithium ion batteries (LIB) makes safe shipment of this commodity as bulk cargo on commercial aircraft a concern due to its potential to initiate a fire by thermal runaway and contribute to a fire by burning of the organic electrolytes. Full-scale tests in aircraft have shown that fires involving large quantities of lithium ion batteries as cargo can be catastrophic. To quantify the fire hazard of LIB, work is being conducted at the Federal Aviation Administration to determine the relationship between the energy density of the LIB, self-heating of the LIB due to the release of stored chemical energy during thermal runaway, and the heat released by combustion of the battery components in a fire. The results of these studies will be presented.

9:15

Upholstered Furniture Fire Safety: Recent Findings and Regulations

Marcelo M. Hirschler

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Fire safety requirements for flaming ignition of upholstered furniture or its components have existed in the US (California) since 1975 (CA TB 117) and in the UK since 1988 (BS 5852); they have not changed significantly until recently. In 2013, the state of California eliminated upholstered furniture open flame ignition requirements and in 2014, the UK started a process that involved questioning their requirements. These changes in requirements are likely to decrease fire safety and increase fire losses, since upholstered furniture fires cause a large fraction of fire fatalities, disproportionate to their fraction of overall fire incidents.

Studies have long shown that making furniture in which all components fully comply with BS 5852 (typically crib 5) will result in excellent fire safety and no transition to flashover. Work has also shown that simply using polyurethane foam that meets the traditional CA TB 117 flaming test would not prevent flashover once the furniture has fully ignited.

Recent studies of the effects of fires from single, small and large upholstered furniture items have shown, once again, how rapidly a small fire can lead to flashover in a room. In particular, an example will be shown how a furniture fire can cause an entire large house to burn to the ground rapidly. It has also become clear that simply adding enough flame retardants to the padding (typically polyurethane foam) will have a significant effect on time to flashover (or even on whether the item actually ignites) and that adding enough flame retardants to both padding and fabric can result in the upholstered furniture item not even reaching flashover. Moreover, appropriately adding flame retardants to plastics has now been shown to decrease heat release, the key fire hazard property.

This session will show the critical nature of fire safety requirements for flaming ignition of upholstered furniture and puts all aspects discussed above into perspective.

9:45

Material Selection Influence on the Flammability of Upholstered Furniture: Demonstrating the Effectiveness of Flame Retardants

Marshall Moore, Carl Powell, [Subramaniam Narayan](#)

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Over 80% of all furniture fires in the United States start with either open flames or smoldering materials¹. For nearly forty years, California's furniture flammability standard, Technical Bulletin 117, required resilient filling materials in upholstered furniture to be tested for resistance to ignition from both smoldering cigarettes and small open flames, such as matches and candles. A recent revision to this standard, Technical Bulletin 117-2013, requires that the cover fabric, barrier material, and filling materials be tested only for cigarette ignition resistance with no consideration to resistance to open flame ignition sources. Since more than 20% of all fires where furniture is the first item ignited are started with a small open flame², it is important to understand how the recent change in California's standard may impact the open flame resistance of furniture. At the national level, the National Fire Protection Association (NFPA) has initiated procedures to develop a new test standard to address ignition from open flame sources³. Concurrently, ongoing research and rulemaking at the Consumer Product Safety Commission (CPSC) is focused on validating approaches to address both smoldering and open flame ignition sources⁴.

While there is a wide array of materials and construction methods employed in the manufacture of residential upholstered furniture (RUF), perhaps the most common includes flexible polyurethane foam (FPUF) covered with a fabric, separated by various types of liner materials. Recent studies^{5,6} on the flammability of upholstered furniture indicate the ignitability and rate of fire development is influenced by the selection of fabric, filling, and liner materials. At Great Lakes Solutions' Application Research Laboratory, studies have been conducted to provide an additional understanding of how the selection of materials in each of these layers contributes to the ignitability and rate of fire development^{7,8}. Utilizing an adaptation of the British Standard 5852 furniture flammability test, using Ignition Source 1 (small flame ignition source), tests were conducted to study variables such as natural versus synthetic content of the fabric, flame retardant (FR) treatment of the fabric or FPUF, flame retardant formulation in the FPUF, and performance of polyurethane versus polyester liner materials. This paper will present results that demonstrate the effectiveness of flame retardants in suppressing ignition, and reducing the rate of fire development when an appropriate FR formulation is used in combination with varying fabric compositions.

¹National Fire Protection Association (2013, September). *White Paper on Upholstered Furniture Flammability*.

²Ahrens, Marty (2011, August). *Home Upholstered Furniture Fires, NFPA Fire Analysis and Research*. Quincy, MA. <http://www.nfpa.org/~media/Files/Research/Fact%20sheets/UpholsteredFactSheet.pdf>.

³NFPA 277: *Standard Methods of Tests for Evaluating Fire and Ignition Resistance of Upholstered Furniture Using a Flaming Ignition Source*. <http://www.nfpa.org/codes-and-standards/document-information-pages?-mode=code&code=277&tab=about>.

⁴Khanna, R. (2013, April). *Overview of the Commission's Recent Activity on Furniture Flammability Rule Making*. <http://www.slideshare.net/USCPSC/presentation-1-rik-khanna>.

⁵Blais, M., Hirschler, M., Janssens, M. (2013, January). *Fire Performance of Polyurethane Foam: California Technical Bulletin 117 and British Standard BS5852*. *Fire and Materials 2013*, pages 319-330.

⁶Fabian, T., Ph.D. (2013, January). *Research Report: Upholstered Furniture Flammability*. Underwriters Laboratories Inc.

⁷Moore, M. (2014, May 21-22). *Strategies for Furniture Fire Safety Solutions*. Presented at Leadership Summit Furniture Flammability and Human Health, Underwriters Laboratories Inc.

⁸Moore, M., Powell, C., Campbell, R. (2014, September 22-24). *Furniture Fire Safety Solutions: A Study on the Open Flame Ignition Resistance of Upholstered Furniture*. Presented at 2014 Polyurethanes Technical Conference, Center for the Polyurethanes Industry.

10:15 – COFFEE BREAK

Chairperson: John Yao

10:45

Reformulating Targeted Materials: How This Impacts Aerospace OEMs

[John N. Harris](#)

Associate Technical Fellow, Thermoplastics Lead Engineer, Boeing Research & Technology, Payloads Tech Dev & IRC/ESRC Supt, (206) 544-1517. john.n.harris@boeing.com.

Meeting the material property requirements associated with aerospace applications that use non-metallic materials can be a challenge that often requires the use of additives. The use of additives to impart property improvements can often be further challenged by regulatory actions that may require their removal from complex formulations. Additives that have been targeted as environmentally hazardous usually comprise only a small percentage of a material formulation. However, finding suitable replacements for additives that have been targeted is often a difficult and expensive task in aerospace due to the constraints imposed by the full set of material property requirements. It also needs to be understood that any activities directed towards materials reformulation do not constitute more than a small fraction of the total costs imposed by new regulations. Much of this cost is from engineering work that has been triggered by a design change that captures the change in material configuration. This engineering is needed to provide definition of the new material configuration and is a fundamental requirement for aerospace OEMs. Minimizing these costs as well as others that arise from environmental regulations in the future will require a more strategic approach to the use of additives, such as flame retardants, and in the design of more sustainable material systems for aerospace applications.

11:15

The Changing Landscape for Flame Retardants: Green Chemistry, Voluntary Environmental Standards, and Public Perception

[Tim Earl](#)

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Flame retardants have played an important role in fire safety for decades. Many modern materials used in building construction and consumer products would not be able to meet the minimum level of fire safety established in codes and regulations without the use of flame retardants.

Public opinion about the chemical industry in general, and flame retardants in particular, has changed significantly over the past few decades. As a result, flame retardants are subject to much more scrutiny now than in the past. New requirements, often issued as voluntary environmental standards, are being developed at a rapid pace. Many of these standards restrict, either implicitly or explicitly, the use of flame retardants, with little thought given to how such restrictions might affect compliance with existing fire safety regulations or fire safety in general.

This session will explore in detail these new requirements and the portrayal of flame retardants in the media, and discuss the implications for those involved in flame retardant research and development.

11:45

Comprehensive Evaluation of Unreacted Flame Retardants in Printed Circuit Boards

Feng Yang and Gordon L. Nelson

Florida Institute of Technology, 150 W. University Blvd, Melbourne, FL 32901. fyang@fit.edu.

Tetrabromobisphenol A (TBBPA) as a reactive brominated compound, is widely used in epoxy resin printed circuit boards in the form of chemically bonded components. It covalently reacts with the epoxy resin backbone and becomes a part of the epoxy resin base material. TBBPA is the predominant flame retardant used in printed circuit boards worldwide. However, the concerns about whether or not flame retardants like TBBPA will migrate out and accumulate in the environment or the human body need to be addressed to fully understand the potential environmental and human impact of this flame retardant.

TBBPA has similar structure as bisphenol A except the bromo substitution at 3, 3' and 5, 5'. Due to the substitution at these positions, the reactivity of the two hydroxyl groups on TBBPA is different than those on a bisphenol A. Therefore, whether or not these hydroxyl groups will completely react with an epoxy backbone or other base polymeric backbone materials is uncertain.

In this research, methods to detect unreacted TBBPA in different types of printed circuit boards have been developed, and the relative ratio of reacted and unreacted TBBPA have been measured by following appropriate IPC standards or modified IPC standards.

12:00

Flame Retardant Chemicals: Technologies and Global Markets

Marcanne Green

BCC Research Chemical Engineering Analyst

The flame retardant market is expected to exceed 2.5 million tons by 2019. Plastics applications (which includes electronics, packaging, automotive/aerospace, foam furniture, building related, medical related, etc.) will continue to dominate the applications of flame retardant chemicals expecting to consume approximately 50% of the market by volume and 70% by value. All other sectors will experience some year over year growth, but not at the pace of plastic related flame retardant chemicals by 2019. Recently there have been declines in oil prices and plastic pricing. Both of these factors should result in higher profits and lower costs for flame retardant chemical and end market producers as many are petroleum based. Oil companies are estimating prices may stay around \$50/barrel through 2020.

Aluminum trihydrate (ATH) will continue to dominate by volume estimated to reach 45% market share by 2019 as a result of growth in plastics. Additional growth for ATH will be in the textiles industry which should account for 22% of the market in volume by 2019. This shift to ATH is expected as halogenated flame retardants (bromine and chlorine) are being phased out. Bromine is expected to see declines in usage. Opportunity exists for phosphorus based products or halogen replacements as a result.

Job growth has begun to improve in construction (industrial, commercial and housing) which results in improved sales in textiles, coatings, paper and decorations – all of the flame retardant related industries. These applications are expected to experience some growth, especially in China and Asia.

China will continue to be dominate growth for product demand. Especially in the plastics, electronics and textiles industries where it is expected China will account for at least 30% market share in both plastics and textiles consumption thru 2019. However, manufacturing of flame retardant chemicals and products that use them may decline in China. This will be primarily due to environmental issues and competition elsewhere in the world. North America, the European Union and the rest of Asia is expected to experience growth in plastics consumption also as housing recovery continues.

Paint, coatings and decorations all are related to the construction and housing market will be driven by job growth in the U.S. and throughout Europe and the Rest of the World. Recent declines in oil prices may lead to a recession or shift in jobs in the U.S. since much of the job growth since the Great Recession of 2009 has been oil industry related. Many oil industry insiders are concerned if oil price are too low it, it may lead to layoffs in the oil related job sector in Canada and the U.S. However, if oil price reductions remain in a safe zone, it is estimated job growth in other sectors will improve, thus generating demand for consumer goods elsewhere.

The changes to California Technical Bulletin 117-2013 and SB 1019 becoming effective January 1, 2015 may have a long term effect on the flame retardant industry, especially in applications to textiles and furniture. Although highly controversial, if proven successful, this easement on flame retardant requirements could cross over to other areas. Several CA based government entities and public and private firms are considering opting out of flame retardant chemicals in furniture in their offices and buildings as a result of California 117-2013 and SB 1019 changes. Currently there are bills proposed throughout the U.S. requesting lower limits or altogether banning a flame retardant chemical. If these regulations are passed, it may lead to additional reductions in usage of certain flame retardant chemicals like Antimony Oxide. Overall, regulations are becoming global as smaller countries adopt or adapt to regulations from the EU or U.S. It is expected that regulation will increase in both India and China in response to higher worker visibility, recent plant fires/catastrophes and competition for manufacturing in other emerging countries such as Vietnam.

New technology appear to be modifications to current formulations of flame retardants which make them “greener”. Evidence of change includes capital investments by major suppliers as they switch manufacturing to new formulations or reformulations of older flame retardant chemicals. Several new technologies are just emerging in the initial patent stages. Most have applications to textiles.

Overall, the industry growth will depend upon growth in jobs and housing, which will drive demand for products that are flame retardant (electronics, automobiles, textiles, decorations, coatings, etc.). Currently, housing starts have improved and construction is experiencing growth in the U.S. and abroad. However, it is possible if banking rates rise at a faster pace than jobs, housing could pull back. In addition, housing experts are knowledgeable in the U.S. of shadow inventory from foreclosures since 2009. If housing improves, it is expected the shadow inventory may be added to the market, competing with new construction. Although this will affect the new construction related sector, it will most likely have a positive impact on products related to home purchases, remodeling and upgrading (appliances, decorations, paints, flooring, etc.) in the housing industry.

12:15

Towards an Improved Bench-scale Smoldering Scenario for Upholstered Furniture

Mauro Zammarano, William M. Pitts, Szabolcs Matko, Douglas M. Fox, Rick D. Davis

Engineering Laboratory, National Institute of Standards and Technology, Gaithersburg, MD, USA; mauro.zammarano@nist.gov

Smoldering poses a serious fire hazard. A large number of residential fire deaths can be attributed to smoldering materials, such as flexible polyurethane foams (FPUFs), commonly found in upholstered furniture and bedding [1].

Smoldering of residential upholstered furniture (RUF) is a complex problem that varies based on the properties of the components (e.g., FPUF, cover fabric, etc.), the layering sequence of the components and the construction of the product. It follows that the possible combinations are almost limitless and, thus, real-scale testing for assessing the smoldering propensity of RUF is not an economically viable solution [2].

Bench-scale tests are more economically feasible than real-scale tests but might not represent a realistic smoldering scenario [3]. Here, we propose real-time temperature logging as a simple technique for characterizing the smoldering behavior and identifying a realistic bench-scale smoldering scenario for upholstered furniture.

[1] Ahrens M. Home structure fires that began with upholstered furniture. Quincy, MA: National Fire Protection Association; 2011.

[2] Gann RG. The challenge of realizing low flammability home furnishing. In: 13th international fire science and engineering conference. London: Interscience Communications; 2013.

[3] Zammarano M, Matko S, Pitts W M, Fox DM, Davis RD, Polymer Degradation and Stability 106 (2014)

12:45 – 2:00 LUNCH



Session 2: Foams and Fabrics

Chairperson: Hongdian Lu

2:00

Preparation of Flame-Retardant and Smoke-Suppressing Expanded Polystyrene Foams

Yuan-Wei Yan, Jian-Qian Huang, Yu-Zhong Wang, Dr. Wang Liao

Center for Degradable and Flame-Retardant Polymeric Materials, College of Chemistry, State Key Laboratory of Polymer Materials Engineering, National Engineering Laboratory of Eco-Friendly Polymeric Materials (Sichuan), Sichuan University, Chengdu 610064, China. yzwang@scu.edu.cn.

Flame-retardant expanded polystyrene (EPS) foams were prepared via coating the flame retardants onto expanded polystyrene spheres. The flame-retardant coating is composed of thermoplastic phenolic resin (PF), curing agent, and flame retardants (FR). The flammability of the coated EPS foams was investigated using the limiting oxygen index (LOI), vertical burning test (UL-94) and cone calorimeter test. The flame-retardant mechanisms were also investigated by SEM, XPS, and Raman spectroscopy. The results show that the coated EPS foam with an optimized formulation has a LOI value of 28% and can pass UL-94 V-0 rating with a density of ~50 kg/m³. The heat release rate (HRR) and the mass loss rate (MLR) of the coated EPS foams are significantly reduced. Interestingly, the smoke production rate (SPR) and the total smoke production (TSP) of the coated foams are also decreased greatly. The coated EPS foams have good mechanical properties and excellent thermal insulation properties. In this session, we will also present a comparative result with the coated EPS foams using expandable graphite as a flame retardant.

2:30

Unconventional Additives to Achieve Ultra-Low Smoke Performance in Polyurethane Foam Insulation

Gus Ibay

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In continuation of past efforts to achieve ultra-low smoke in polyurethane systems, a liquid component designated Additive X was found which has potential to achieve ≤50 Smoke Density Index and ≤25 Flame Spread In-

dex. This is based on a predictive model using Cone Calorimeter. Previous work has shown that while it is possible to achieve low smoke with fillers such as ATH and melamine, physical properties are compromised as well as thermal resistance. The approach was to produce a high index polyurethane system containing polyols with high aromatic content. This session will present the results from the use of Additive X in foam systems at various isocyanate indices, polyol aromaticity, and varying blowing agents.

3:00

Combination of Gas and Condensed Phase Effect of Phosphorus Flame Retardancy in Polyisocyanurate Foam

Hongyu Yang ^{1,2}, Lei Song¹, Yuan Hu¹, Richard K.K. Yuen ²

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²*Department of Architecture and Civil Engineering, City University of Hong Kong, Tat Chee Avenue Kowloon, Hong Kong.*

Nowadays, building exterior wall thermal insulation materials are widely used for energy conservation and consumption reduction. However, most of the recent building fires were caused by the ignition of flammable polymeric foam. Therefore, flame-retardant research of thermal insulation materials has attracted enormous attention. Rigid polyurethane foam is one of them. To impart polyurethane foam with satisfactory flame-retardant performance, numerous attempts have been made. For instance, many organic/inorganic flame retardants containing halogen (chlorine, bromine), phosphorus, nitrogen, silicon, boron, etc. were introduced into polyurethane foam to improve its flame retardancy. Halogenated flame retardants had been banned in many countries due to their heavy smoke production and environmental disruption during fires. The trend is now toward halogen-free flame retardants.

Among the halogen-free flame retardants, phosphorus-containing compounds are considered one of the most effective flame retardants. These compounds mainly act on condensed phase flame retardant mechanisms as dehydration and carbon-forming catalysts or act on gas phase flame retardant mechanisms as radical scavenger.

In order to obtain better flame retardant effects in halogen-free polyurethane foamy systems, first, polyisocyanurate foam (a special rigid polyurethane foam), which possess a lot of isocyanurate rings and excellent thermal stability, was chosen as a foam matrix. Simultaneously, some phosphorus flame retardancy were selected to study their synergistic flame-retardant effect on polyisocyanurate foam. The flame-retardant effects have been investigated through means of cone calorimeter, LOI test, and thermogravimetric analysis (TGA). Scanning electron microscopy (SEM) and X-ray photoelectron spectroscopy (XPS) were employed to characterize the morphology and composition of the char residues. The flame retardant mechanisms were investigated by thermogravimetric analysis/infrared spectrometry (TG-IR) and in situ Fourier transform infrared spectroscopy (in situ FTIR).

3:30 – COFFEE BREAK

Chairperson: Walid Awad

4:00

Vertical Cone Calorimeter Testing of Polyurethane Foams

Mary L. Galaska, Alexander B. Morgan, Kathleen A. Schenck, John G. Stalter

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Of concern to regulators and fire safety engineers is how flexible polyurethane foam drips and flows during burning. Specifically, flexible polyurethane foam forms a burning “pool” of liquid as the foam decomposes, which can lead to accelerated flashover events. To fully study this phenomena where the “pool

fire” accelerates heat release, large scale tests like the furniture calorimeter (ASTM E1537) are used and no small scale technique exists. In this session, we will present our work in developing a new sample holder that works with a bench scale heat release test, the cone calorimeter (ASTM E1354). The holder was built upon designs developed by the National Institute of Standards and Technology (NIST), which placed the foam in a cage in a vertical orientation during cone calorimeter testing. In this session we show the schematics for this test apparatus, as well as results obtained with this apparatus on four different flexible foams (shape memory and high density foam, flame retarded and non-flame retarded). We compare the results from the vertical testing to that obtained via traditional horizontal ASTM E1354 testing. Advantages and disadvantages of this new apparatus will be discussed.

4:30

Nonformaldehyde Flame Retardant Finishing of 65/35 Nomex/Cotton Blend Fabric for Protective Clothing

Charles Q. Yang and Qin Chen

Department of Textiles, Merchandising and Interiors, The University of Georgia, Athens, GA 30602, U.S.A.

Due to excellent fire-resistant properties, Nomex has commonly been used to produce protective clothing. However, the high cost and low comfort of Nomex have limited its wider uses. Blending Nomex with cotton not only reduces the cost but also improves comfort of the finished fabrics. Because cotton is a highly flammable fiber, the Nomex/cotton blend fabric containing more than 20% cotton is not self-extinguishable. Therefore, a durable flame-retardant finishing treatment becomes necessary to make the Nomex/cotton blend flame hydrolysis-resistant if the blend contains more than 20% cotton fiber.

Previously we developed a flame retardant finishing system for cotton based on a hydroxyl-functional organophosphorus oligomer (HFPO) with 20.5% phosphorus content. Because HFPO does not have a reactive functional group for cotton, it is necessary to use a bonding agent to bond HFPO to the cotton fiber. In this research, we used 1,2,3,4-butanetetracarboxylic acid (BTCA) as the bonding agent because BTCA can esterify both cellulose and HFPO. BTCA has been used as a nonformaldehyde durable press finishing agent for cotton to produce wrinkle-free cotton textiles. We studied the bonding of the HFPO/BTCA system on the 65/35 blend. We found that close to 90% of the HFPO/BTCA system applied to the blend was chemically bound to the blend and increased the fabric stiffness after treatment. The data suggests that HFPO was probably bound to the blend by forming a self crosslinked polymeric network on the blend in addition to forming a BTCA bridge between cotton and HFPO.

When the Nomex/cotton fabric was treated with the combination of HFPO and BTCA with NaH_2PO_2 as the catalyst, the char length was reduced drastically to 30-50 mm range and the LOI was increased to 28-31% at a relatively low HFPO concentration (8%) on the fabric. However, the free carboxylic acid groups on the Nomex/cotton blend fabric treated with HFPO/BTCA formed insoluble salts when the treated fabric was washed in water containing calcium ions. Deposit of calcium salt on the fabric diminished the effectiveness of HFPO by increasing the char length for the fabric vertical burning test and reducing LOI of the treated Nomex/cotton blend fabric. When triethanolamine (TEA) was present in the system, esterification between the free carboxyl group of BTCA and the hydroxyl of TEA took place, thus reducing the calcium deposition during multiple launderings. TEA also improved the effectiveness of HFPO by providing synergistic nitrogen. Consequently, inclusion of TEA in the formula significantly increased the flame retardant performance of treated blend fabric. The Nomex/cotton blend fabric treated with HFPO/BTCA/TEA was able to achieve very low char length (~40 mm) for the fabric vertical burning test when a low concentration (8%) of HFPO was used. The treated blend maintained high flame retardancy (66 mm char length) after 25 home laundering cycles. The HFPO/BTCA/TEA system

caused modest decrease in fabric tensile and tearing strength and modest increase in fabric stiffness. The heat release rate data was consistent with the macroscopic flame retardancy performance of the treated blend.

5:00

Water-Soluble Polyelectrolyte Complexes and Layer-by-Layer Assemblies as Environmentally-Benign Flame Retardant Nanocoatings

Jaime C. Grunlan

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This session will highlight new flame retardant (FR) nanocoatings, prepared from aqueous polyelectrolyte complexes or layer-by-layer thin film assemblies. Both technologies are being developed within the Polymer NanoComposites (PNC) Laboratory (<http://nanocomposites.tamu.edu/>) at Texas A&M University. In an effort to quickly impart flame retardant behavior to cotton fabric, and in an environmentally-benign manner, a water-soluble polyelectrolyte complex (WPEC) was evaluated. A One-Pot mixture consisting of polyethylenimine and poly(sodium phosphate) imparts self-extinguishing behavior in a single step. This nanocoating maintains the fabric's weave structure by conformally coating individual fibers. Appreciable weight gain (23%) is achieved with just a single 30 s immersion in the WPEC suspension. Treatment of this coating with acidic buffer further renders it insoluble in water and durable to rinsing. Uncoated cotton is readily consumed during vertical flame tests, while OnePot-coated fabric, followed by buffer treatment of pH 5 or lower (16.5% weight gain or less), self-extinguishes through an intumescent mechanism. Microscale combustion calorimetry reveals a total heat release reduction of 88% and peak heat release rate reduction of 81%. This work demonstrates the ability of a WPEC nanocoating to prevent ignition of cotton fabric with few processing steps, relatively low weight gain, and environmentally-benign ingredients. New advances in our layer-by-layer assembly of polyelectrolytes on blended fabric will also be described. Nylon/cotton and polyester/cotton blends can now pass vertical flame testing with as few as six bilayers, with comparable weight gain to those obtained for the complexes described above. There are now two commercially-feasible, water-based coating technologies that impart environmentally-benign flame retardant treatments to the most commonly used fabric materials.

5:30

Observing Smoldering-to-Flaming Transition on Foam/Fabric Assemblies

Stanislav I. Stoliarov¹, Alexander B. Morgan², Sergei Levchik³

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A transition from smoldering to flaming is a significant concern for regulatory agencies responsible for developing and enforcing fire safety standards for furniture. This phenomenon is poorly understood because of its sensitivity to a multitude of physical parameters and a lack of bench scale experiments where it can be observed under controlled and reproducible conditions. Here we report on development of a new apparatus which enables observation of this transition using a relatively small sample consisting two 5x20x30 cm flexible foam blocks wrapped in a fabric of interest. In this apparatus, smoldering process is initiated using a local electric heating and gradually intensified due to self-heating and resupply of oxygen driven by natural convection. For a combination of a widely used flexible polyurethane foam and cotton fabric, this experiment yields a reasonably

reproducible transition. It is also demonstrated that this experiment can be employed to discriminate between various foam/fabric compositions in terms of their propensity to transition to flaming.

6:00

Environmental Friendly Flame Resistant Coatings for Soft Furnishing

Yeon Seok Kim, Yu-Chin Li, You-Hao Yang, John Shield, and Rick Davis*

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Pending flammability regulations and scrutinizing of the environment and health consequences of fire retardants is creating opportunities for novel and “greener” technologies to reduce the flammability of residential furniture. This presentation will discuss bio-based fire resistant coatings applied to flexible polyurethane foam and fire blocking barrier fabrics. The waterborne coatings were fabricated using Layer-by-Layer assembly and an innovative one-step/one-pot process and were constructed from common natural materials. The coatings caused significant reductions in the flammability (e.g., heat release, ignition propensity, and flame spread) of these substrates. When used in full-scale fire tests, the coated foam caused as high as a 75% reduction in peak, total, and average heat release of furniture.

6:30-8:00 – RECEPTION

Tuesday, May 19

7:00 - 8:00 – BREAKFAST



Session 3: Nanocomposites

Chairperson: Chandrasiri Jayakody

8:00

Thermal Properties and Flammability Performance of Polystyrene/Carbon Nanotube/Zirconium Phosphate Composites

Hongdian Lu, Jin Liu, Wei Liu

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Polystyrene/zirconium phosphate/carbon nanotubes composites (PS/ZrP/CNTs) were synthesized via in situ emulsion methods. Morphology and dispersion of the ZrP and CNTs within the polymeric matrix were carried out by X-ray diffraction (XRD) and transmission and scanning electron microscopy techniques. It was established that the dispersion of ZrP and CNT in PS was excellent. Thermal properties and flammability behavior of PS/CNT/ZrP composites were evaluated by thermogravimetric analyses (TGA) and microscale combustion calorimetry (MCC). Synergy was observed when CNT was incorporated into the PS/ZrP system to impart the composites' increased thermal stability and flame retardancy.

8:30

Copolyester-Clay Nanocomposite Additives for Flame Retardant Applications

Robert Young, Principal Applications Development Engineer; Jeff Galloway, PhD, Senior Applications Engineer; Casey Halsey, Technician

Eastman Chemical Company, Polymers Technology - Specialty Film and Sheet, Kingsport, TN 37662. Phone: 423-229-3159; Mobile: 423-292-9790; Fax 423-224-0413. ryoung@eastman.com.

Flame Retardant plastics are a growing need of numerous markets including fibers, composites, electronics, transportation and medical. For polymers

that are not inherently flame retardant, such as copolyesters, additives are used to impart flame retardant properties. Eastman has developed a flame retardant additive, Eastman Spectar[™] FR1000, for polyester and copolyester resins. Achieving a robust UL – 94 V0 rating is very desirable and is difficult to obtain due to the intrinsic flow properties of copolyesters. The use of clay nanocomposites such as Montmorillonite and Halloysite have been documented in the literature to improve various physical properties such as mechanical, barrier, and thermal expansion, and had been investigated in the past by Eastman, but not extensively for flame retardant properties. This session will discuss some recent work performed by Eastman, looking at Montmorillonite and Halloysite in copolyesters and their effects on physical and flame retardant properties.

9:00

Study on the Flame Retardancy of Sulfonate-containing Polyhedral Oligomeric Silsesquioxane (S-POSS)/ Polycarbonate Composites

ZiQian Li, Rongjie Yang

National Engineering Research Center of Flame Retardant Materials, School of Materials, Beijing Institute of Technology, Beijing 100081.

A kind of sulfonate-containing polyhedral oligomeric silsesquioxane (S-POSS) was synthesized using sulfonation of octaphenylsilsesquioxane by chlorosulfonic acid and potassium carbonate, and characterized by FTIR and 1H-NMR spectroscopy. A series of polycarbonate (PC) composites were prepared by incorporation of S-POSS via direct melt blending. The thermal and mechanical properties of composites with different S-POSS loadings were investigated by DSC, TGA and tensile tests. The presence of S-POSS led to a tiny decrease of the glass-transition temperature. However, the initial thermal degradation temperatures of composites decrease obviously. The flame retardancy performance of composites was studied by LOI and UL-94 burning test. The composite had an LOI value of 33.3 and a UL-94 rating V-0 (3.2 and 1.6 mm) with the content of S-POSS at 0.25%. The pyrolytic gaseous products of the polycarbonate with and without S-POSS are detected by TGA-FTIR. Releases of gaseous species are found to be similar for the PC control and flame retarded PC. The details of fire behaviors, such as TTI, HRR, p-HRR, TSR, SEA, COPR, CO2PR, and TML, are tested by cone calorimeter. The flame retardancy mechanism of S-POSS in the polycarbonate composites are explained in detail in this research.

9:30

Flame Retardancy of Chemically Modified Lignin as Functional Additive to Epoxy Nanocomposites

John A. Howarter^{1,2}, Gamini P. Mendis¹, Alex N. Bruce¹, Jeffrey P. Youngblood¹, Mark A. Dietenberger³, Laura Hasburgh³

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The ability to create polymeric composite materials using alternative bio-based feedstocks such as lignin while maintaining core epoxy material properties such as high strength, high thermal stability, and high working temperatures is an area of great interest for structural, electronic, and adhesive applications. Furthermore, by chemically modifying the lignin additives, it may be possible to enhance flame retardancy. We investigated epoxy based nano-composite materials that contained non-halogenated wood-derived fill material (e.g. lignin) which could serve as both structural/mechanical reinforcement and a thermally resistant additive. Processing conditions were varied to investigate the relationship between total filler

content, surface functionality, and ability to incorporate the filler into a homogenous composite material. We will present findings on epoxy-lignin composites made with various lignin pretreatments, with a specific focus on the role of lignin hydration in the processing and performance of the composite material. Our results indicate that there is an optimal degree of hydration that will minimize both lignin agglomeration during processing and also minimize the particle size of the secondary material phase, thus creating a more homogenous composite material. Materials were characterized for mechanical performance using dynamic mechanical analysis along with ASTM standard fracture toughness measurements. Thermal performance was measured with gravimetric analysis and differential scanning calorimetry. Flame retardancy was investigated with limiting oxygen index tests, vertical burn tests and cone calorimetry.

10:00 – COFFEE BREAK

Chairperson: Alex Morgan

10:30

Improving Fire Safety of Polypropylene/Carbon Fiber Composites by Adding Nanosized Carbon Materials

Jiang Gong^{1,2}, Hongfan Yang^{1,2}, Xin Wen¹, Tao Tang^{1*}

¹State Key Laboratory of Polymer Physics and Chemistry, Changchun Institute of Applied Chemistry, Chinese Academy of Sciences, Changchun 130022. ttang@ciac.ac.cn.

²University of Chinese Academy of Sciences, Beijing 100049, China.

Polymer/carbon fiber (CF) composites have excellent mechanical properties, such as high specific strength and modulus, good fatigue, and corrosion resistance. So these composites have become attractive alternatives to conventional metallic materials in many application fields such as aircraft, ships, buildings and transportation. However, polymer/CF composites show poor fire safety due to their combustible nature. Consequently, improving the flame resistance is crucial to increase the utilization of polymer/CF composites. The combination of fillers with different size and geometrical dimensions to make a synergistic effect on improving the flame retardancy and other properties (such as mechanical, electrical and thermal performance) seems to be an effective and efficient way to make high-performance multifunctional composites. In this session, we demonstrate a promising method to improve fire safety of polypropylene (PP)/CF composites via introducing nanosized carbon black (CB) and carbon nanotubes (CNTs). Compared to PP and PP/CF composites, the presence of CNTs or CB dramatically reduced the values of PHRR, THR and TSP, while the LOI is increased. Furthermore, we have found that the combination between chlorinated CF and Ni₂O₃ can further decrease the THR and TSP due to in situ conversion of degradation products from PP into CNTs. The mechanism for improving fire retardancy was partially from the accelerated oxidation crosslinking reaction of PP radicals by CB or CNTs (chemical effect), and partially to the in situ formation of a dense and continuous CF/CNT (or CB) hybrid protective layer (physical effect). It is believed that this work opens up a new opportunity for fabricating multiscale hybrids to improve physical and chemical properties of polymeric materials.

11:00

Self-Assembly of Mesoporous Silica@Ni-Al Layered Double Hydroxide Spheres for Reducing Fire Hazards of Epoxy Resins

Shu-Dong Jiang¹, Lei Song¹, Yuan Hu^{*1,2}

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Mesoporous silica@Ni-Al layered double hydroxide (m-SiO₂@Ni-Al LDH) spheres were prepared through a self-assembly process, with the purpose of combining their excellent physical and chemical characteristics. TEM results showed that, due to the electrostatic potential difference between m-SiO₂ and Ni-Al LDH, m-SiO₂ spheres were coated by the Ni-Al LDH nanosheets. Subsequently, the m-SiO₂@Ni-Al LDH hybrids were incorporated into an epoxy resin (EP) matrix to prepare specimens for investigation of reduced fire hazard behavior. Cone results indicated that m-SiO₂@Ni-Al LDH incorporated obviously improved fire retardant behavior of EP. Moreover, the amount of organic volatiles from epoxy resin decomposition was significantly reduced, and the formation of toxic CO was suppressed, implying a reduced fire hazard. A plausible mechanism was speculated based on the analyses of thermal conductivity, char residues and pyrolysis fragments. Labyrinth effects of m-SiO₂ and graphitized carbon char formation catalyzed by Ni-Al LDH play key roles in the reduced fire hazard.

11:30

Micro-Scale Study on the Flammability of Polymers

Hsinjin Edwin Yang, Pioneer Scientific Solutions; Frederick P. Schall, Deatak Instruments.

fred.schall@deatak.com

Flammability, which generally refers to the propensity of a material to ignite easily and burn rapidly with a flame, is an indicator of fire hazard. Polymer flammability evaluations are important and critical for compliance with certain fire codes, fire regulations and for general fire safety. Currently, the UL 94 test, a macro-scale Bunsen-burner ignition test, is widely applied for the classification of plastics flammability from lowest (least flame-retardant) to highest (most flame-retardant) with the classifications, e.g. from V0, V1, V2 to HB. However, the UL 94 test results are qualitative evaluations of flammability by observation.

Recently, the Micro-scale Combustion Calorimeter (MCC) has been developed to scientifically and quantitatively study polymer flammability characteristics such as ignition temperature, combustion temperature, heat release rate (HRR), heat release capacity, and total heat of combustion. In this session, the MCC technique is applied to investigate the flammability behavior of some popular polymers; e.g., PVC, fluoropolymers, polyolefins (PE, PP), polyester, and to further develop the correlation between MCC results and other flammability tests; e.g., UL 94 rating, Limited Oxygen Index (LOI) and Cone Calorimeter. Additionally, the development of calibration method, testing methods and procedures, and the degree of flammability will be discussed.

12:00

Some Findings of Fire Retarding Polymer Nanocomposites

De-Yi Wang

Madrid Institute for Advanced Studies of Materials (*imdea-materials*), c/ Eric Kandel, 2, Getafe (Madrid) 28906, Spain. deyi.wang@imdea.org.

Polymeric materials are widely used in different industrial fields. However, due to their high flammability, in many of these applications there exists severe risk of fire-related casualties and loss of valuable property. Therefore, it is often necessary to make these products more fire retardant by using suitable fire retardants in the original materials. In last few decades, it had been recognized that the formation of nanocomposites can improve the fire retardant performance at relatively low filler loadings.¹⁻³

In this session, some new findings on fire retardant polymer (nano)composites developed in my laboratory in the last two years will be presented. Some new functional nano-fire retardants and new fire retardants designed and developed in my group will be reported. Series polymeric materials, such as PP, Epoxy, and PVC are chosen as polymer matrix. In this session, it is noted that the functional nanomaterials at low loading provide a possibility as an independent excellent fire retardant for polymers, passing

UL-94 V-0 rating. Moreover, the fire retarding polymer nanocomposites also show low heat release rate, low total heat release rate and low smoke production, etc., in the reinforced fire test.

¹Wang DY, Leuteritz A, Wang YZ, Wagenknecht U, Heinrich G. Preparation and flame resistance properties of revolutionary self-extinguishing epoxy nanocomposites based on layered double hydroxides. *Polymer* 2005; 46:9314-9328.

²Wang DY, Das A, Costa FR, Leuteritz A, Wagenknecht U, Heinrich G. Synthesis of organo Co–Al layered double hydroxide via a novel single step self-assembling method and its use as flame retardant nanofiller in PP. *Langmuir*, 2010;26 (17):14162-14169.

³Zammarano M, Franceschi M, Bellayer S, Gilman JW, Meriani S. Preparation and flame resistance properties of revolutionary self-extinguishing epoxy nanocomposites based on layered double hydroxides. *Polymer* 2005; 46:9314-9328.

12:30

Structure-Property Relationships of Polyethylene and Polypropylene Graphene Nanocomposites: Thermo-Mechanical Response and Flame Retardance

Kai Yang, Yichen Guo, Maya Endoh, Radha P. Ramasamy, Molly M. Gentleman, Thomas A. Butcher, Miriam H. Rafailovich

Dept. of Materials Science and Engineering, SUSB, Stony Brook, NY 11795.

Russell Charnoff, Arun Soni, David Choi

Garcia High School Research Program, SUSB, Stony Brook, NY 11795.

We have successfully fabricated nanocomposites with well-dispersed GNPs via melt blending with semi-crystalline polymers, polypropylene (PP) and polyethylene (PE). Thermal conductivity measurements on the nanocomposites indicated that the thermal coefficient scaled linearly with GNP loading in both cases. Values of 2.0W/m²*k and 1.0W/m²*k were achieved at a loading of 40 weight % for PP and PE, respectively. These values, which could not be achieved with conductive particles or carbon nanotubes, opens multiple uses for these compounds in heat exchange units or biofuel storage tanks. Tensile measurements indicated that the modulus increased, linearly with GNPs loading throughout the range tested (1-50% weight percent), while the IZOD impact and toughness decreased initially up to a loading of 10% and then remained constant for up to 50%. The torque required for extrusion increased only by 25% over this range indicating that the compound remained processable despite the high loading content.

The response of the PP compound to a rapidly approaching heat front was also probed using cone calorimetry, where large reductions in the heat release rate and mass loss rates were observed for concentrations larger than 10 weight%. Minimal changes were observed for larger concentrations, though a weight % fraction of 40% was required to render the composite flame retardant according to UL-94-V0 convention. This response was attributed to good thermal conductivity coupled with char forming properties which hindered the oxidation process, as evidenced by the increase in the limiting oxygen index (LOI). The time to ignition though had a parabolic function, initially decreasing and not returning to baseline till loadings higher than 10% were achieved. A similar functional form was also obtained for the electrical conductivity for loadings less than 10%, at which point an abrupt increase by several orders of magnitude was observed, indicating that percolation was attained. The similarity between the two response functions indicated that in contrast to the thermal conductivity which increased monotonically for all concentrations, under equilibrium conditions, rapid dissipation only occurred at percolation.

Structure-property relationships were investigated using x-ray scattering and electron microscopy. SAXS data, together with SEM analysis, indicates that these unusual properties occurred due to the ability of polypropylene to incorporate very large volume fractions of GNPs, causing a transformation

from a filled polymer matrix with GNP inclusions to a Nacre-like nanocomposite, consisting mostly of GNP platelets coated with polymer chains. In contrast, the PE compound consisted of GNP platelets interspersed within the polymer matrix at low loadings and associated large clusters at higher loading. The structure of the PP is consistent with the relatively larger impact toughness at high loading. The WAXS spectra for both compounds indicates that the polymer chains have a high degree of crystallinity, templated on GNP surfaces in the same crystalline phase as those in the neat polymer. In the case of PP the chains favor a somewhat different orientation than the chains within the folded lamellae structure of the neat polymer. The ability of the polymer chains to conform to the graphene platelets was also postulated to enable good phonon coupling, thereby explaining the unusually high thermal coefficients achievable in these compounds.

1:00 – 2:00 LUNCH



Session 4: Phosphorus

Chairperson: Yu-Zhong Wang

2:00

Melamine Poly(metal phosphates) as Flame Retardant in Epoxy Resin: Performance, Mechanisms, Synergy

Patrick Müller, Bernhard Schartel

BAM Federal Institute for Material Research and Testing, Unter den Eichen 87, 12205 Berlin, Germany. bernhard.schartel@bam.de.

Melamine poly(metal phosphates) (MPMeP) are halogen-free flame retardants commercialized under the brand-name Safire®. In this work, three different kinds of MPMeP (Safire® 200, Safire® 400 and Safire®600) were incorporated into an epoxy resin system and the resulting thermosets investigated regarding their properties, thermal decomposition and burning behavior via differential scanning calorimetry, pyrolysis combustion flow calorimetry, UL 94-testing, cone calorimetry and thermo-gravimetric analysis coupled with Fourier-transform infrared spectroscopy. While the materials exhibited mostly similarities regarding their thermal decomposition, their fire behavior differs and the samples containing melamine poly(zinc phosphate) (MPZnP) and melamine poly(magnesium phosphate) show better performance than those containing melamine poly(aluminum phosphate).

MPZnP was incorporated in combination with various other flame retardants at different ratios to search for synergistic effects and promising combinations. A positive interaction was evident with melamine polyphosphate (MPP) and with boehmite. The overall best performance was observed for the thermosets containing MPZnP and MPP.

This research evaluated the efficiency and compatibility of MPMeP as flame retardants in epoxy resins, alone as well as in combination with other flame retardants.

2:30

The Use of Oligomeric Phosphonate to add Fire Protection to Sustainable Polyurethane Foam

Tim Reilly

Clariant Additives. timothy.reilly@clairant.com.

Over the past several years, there has been much discussion and controversy concerning California TB-117. This has resulted in the updated standard CA TB-117-2013. Using commercially available reactive flame retardant technology from Clariant in combination with natural oil polyol solutions from Natural Foam Technology (UK), it is now possible to produce environmentally acceptable foams with high biorenewable content while maintaining resistance to open flame ignition. These new foams provide the possibility of fire safety without impact on human health and the environment.

3:00

Novel Phosphorus Containing Flame Retardants for Engineering Plastics

Manfred Döring

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Engineering plastics (PA, PBT) have their own high processing temperatures (250-350°C and even higher). To realize fire-resistant polymers it is necessary to compound polymers and flame retardants at these temperatures without a serious change in the characteristics of the polymer. Furthermore, a synergistic interaction of condensed phase and gas phase effects often guarantees, particularly for fiber reinforced engineering plastics, maximum flame retardant efficiency.

In this session, commercially available non-halogenated flame retardants for engineering plastics will be presented and their efficiency will be compared. Furthermore, new bridged and polymeric phosphorus containing flame retardants will be introduced, their synthesis and thermal stability will be described and the flame retardant efficiency particularly in synergistic combination will be discussed. Bridged rod-like, star-shape and particularly polymeric compounds are preferred due to their less plasticizing effect and the marginal tendency of migration.

The chemical environment of phosphorous compounds is responsible for the specific flame retardant behavior¹. On the one hand, condensed phase active inorganic as well as organic phosphates are responsible for charring, and on the other hand, a growing part of phosphorus carbon bonds in organic phosphorus compounds increases the gas phase activity of these flame retardants². Due to the structurally benefiting release of P-containing radicals, compounds which contain the heterocyclic 9,10-dihydro-9-oxa-10-phosphaphenanthrene-10-oxide (DOPO) represent particularly efficient gas phase active flame retardants³. A combination of different active functions in one flame retardant compound⁴ or optimized formulations of different active flame retardants achieve excellent fire-resistant solutions for engineering plastics.

1Braun, U; Balabanovich, AI; Schartel, B; Knoll, U; Artner, J; Ciesielski, M; Döring, M; Perez, R; Sandler, JKW; Altstädt, V; Hoffmann, T; Pospiech, D; *Polymer* 47 (2006) 8495.

2Hergenrother, PM; Thompson, CM; Smith Jr, JG; Connell, JW; Hinkley, JA; Lyon, RE; Moulton, R; *Polymer* 46 (2005) 5012.

3Rakotomalala, M; Wagner, S; Döring, M; *Materials* 3 (2010) 4300.

4Wang, J-S; Liu, Y; Wang, D-Y; Ge, X-G; Wang, Y-Z; *Flame Retard. Mater. Tech.* 5 (2005)14.

3:30 – COFFEE BREAK

Chairperson: Yuan Hu

4:00

Synthesis and Flame Retardancy Characterizations of New Bio-Based Phosphorus-Containing Epoxy Thermosets

L. Ferry¹, R. Menard^{1,2}, R. Sonnier¹, C. Negrell-Guirao², G. David²

¹*Centre des Matériaux des Mines d'Alès (C2MA), Ecole des Mines d'Alès, 6 Avenue de Clavières 303019 Alès Cedex France.*

²*Institut Charles Gerhardt, Montpellier, UMR CNRS 5253, Equipe Ingénierie et Architectures Macromoléculaires, Ecole Nationale Supérieure de Chimie de Montpellier, 8 rue de l'école normale, 34296 Montpellier Cedex 5 France. laurent.ferry@mines-ales.fr.*

The last decade has seen a growing interest for bio-based polymers. A lot of works have demonstrated the possibility to develop polymers from renewable resources constituting a credible alternative to oil based poly-

mers. Nevertheless, to improve their functionality polymers are most of the time used with additives. Thus, flame retardants are designed to improve polymers' fire behavior. Therefore, to supply fully eco-friendly materials, there is a need to develop bio-based flame retardant solutions.

In this work, the use of phenolic bio-based compounds was envisaged to obtain new molecules with flame retardant properties. The presence of aromatic structure in the bio-resource was thought to favor charring during polymer combustion. Phloroglucinol, a triphenol that can be isolated from fruit tree bark, was chosen as the basic compound.

In a first step, different organophosphates varying by their R group (methyl, ethyl and phenyl) were grafted onto phloroglucinol hydroxy groups. These molecules were incorporated in an epoxy (DGEBA/IPDA) matrix as flame retardant additives and the thermal and flammability properties of the thermoset were assessed.

In a second step, the phenolic bioresource was first epoxidized using epichlorhydrin before being modified by phosphorous compounds. In this case, a molecule bearing both a reactive group and a phosphorous group was obtained. This molecule was used as reactive flame retardant in the above-mentioned epoxy matrix by partial to complete substitution of DGEBA. An up to 80% bio-based flame retarded material could be obtained, for which thermal and flammability properties were also characterized.

To go further to 100% bio-based material, the last step could consist of the substitution of IPDA by a bio-based diamine used as crosslinking.

4:30

A Highly Thermally Stable Phosphorus Flame Retardant for Semi-aromatic Polyamides

Qiang Yao, Kai Huang

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Rigid steric hindering spiro-bisphosphates were synthesized from spiro pentaerythritol chlorophosphate and o-alkylsubstituted phenol in order to investigate the effect of steric hindering groups on the flame retardant mechanism of bisphosphates and the effect of rigid spiro pentaerythritol structure on the heat distortion temperature (HDT) of polycarbonate. A comparison of steric hindering spiro-bisphosphates with the simplest phenyl spiro-bisphosphate and commercial resorcinol bis(diphenyl phosphate) (RDP) on the flame retardancy of polycarbonate reveals that the presence of a thermally stable steric hindering group not only changes the efficiency but also shifts the mode of flame retardancy. Compared to PC/RDP, PC/PDMPDP has a high HDT value.

5:00

Flame Retardant Properties of Phosphorus Esters Derived from Isosorbide Di(14-hydroxy-12-thiatetradecenoate)

Bob A. Howell and Yoseph G. Daniel

Science of Advanced Materials, Center for Applications in Polymer Science, Department of Chemistry, Central Michigan University, Mt. Pleasant, MI 48859-0001. bob.a.howell@cmich.edu.

Concerns about the quality of the environment, sustainability and potential toxicity have led to an increasing interest in polymer additives derived from renewable biosources. In particular, flame retardants derived from biosources have several advantages over petrochemical materials. Starting materials are generally nontoxic (sometimes edible) and available from plant sources on an annual basis. Products obtained from these materials are not persistent in the environment and often degrade to innocuous compounds. This is particularly the case for many organophosphorus compounds. Isosorbide di(undec-10-enoate) may be prepared from isosorbide (a starch derivative) and 10-undecenoic acid (derived from castor oil). This ester is doubly unsaturated and may be used as a base for the generation of a series of phosphorus esters which impart good flame retardancy to DEGBA epoxy resin at low phosphorus loading.

Phosphorus-Based Flame Retardant Coatings for Polymers and Composites

Katherine Williams, Piyanuch Luangtriratana, Baljinder Kandola, John Ebdon, A. Richard Horrocks

Institute for Materials Research and Innovation, University of Bolton, Bolton BL3 5AB, UK. kw5mpo@bolton.ac.uk, b.kandola@bolton.ac.uk, j.ebdon@bolton.ac.uk.

For many years, phosphorus has been used as a flame retardant due to its intumescent and char forming properties, with vinyl phosphonic acid proven to work as a flame retardant in textile based applications¹. This knowledge was then taken and used to develop a vinyl phosphonic acid based coating which could be polymerized using UV polymerization techniques onto the surface of a glass fiber - reinforced epoxy composite substrate to act as a flame retardant². In more recent work PMMA has been used as a substrate. Both glass fiber - reinforced epoxy composite and PMMA were chosen as these have extensive use in structural applications and there is a need to preserve the structural integrity of these materials. The focus of this paper is the study of the effect of the substrate on the flame retardant and thermal barrier efficiencies of the coating. In general the polymerized coating showed both excellent adherence to the substrate and flame retardant behavior, displaying impressive intumescent char formation under cone testing which relayed prolonged protection from the source of heat to the substrate below. The cone testing results were very encouraging; with delayed time to ignition at 50 kW/m² and complete lack of ignition at 35 kW/m². However, in weathering tests the coatings did not withstand water soak testing and as such modifications to both the formula of the coating and pre-application modifications of the substrate were tested with a view to improving the performance of the coating in water soak tests.

¹Opwis K., Wego A., Bahners T., Schollmeyer E., Permanent Flame Retardant Finishing of Textile Materials by a Photochemical Immobilization of Vinyl Phosphonic Acid, *Polymer Degradation and Stability*, 96 (3), pp. 393 – 395 (2011).

²Luangtriratana P., Kandola B.K., Ebdon J.R. UV-polymerisable, phosphorus-containing, flame-retardant surface coatings for glass fibre-reinforced epoxy composites, *Progress in Organic Coatings*, in press (2014).

6:00 - 7:30 – RECEPTION

Wednesday, May 20

7:00 - 8:00 – BREAKFAST



Session 5: New Flame Retardants and Specific Polymers

Chairperson: Kelvin Shen

8:00

Anti-Flammable Polymers and Cross-Linked Networks: Difunctional and Multifunctional Deoxybenzoins

Todd Emrick

Polymer Science and Engineering Department, University of Massachusetts, Amherst, MA 01003. tsemrick@mail.pse.umass.edu.

This session will describe monomer and polymer syntheses of difunctional and multifunctional deoxybenzoins, and examine their potential role in the future of non-flammable polymer materials. The deoxybenzoin monomer/polymer family combines key attributes needed for effective polymerization chemistry with an inherently low flammability that is predicted by calorimetric heat release capacity values and verified by larger scale flammability experiments. Lessons learned from this class of monomers are instructive toward the design of new systems that build from this materials platform. Specific systems of interest for this lecture include polyesters, epoxy polymers, and polyurethanes.

Salen-Based Schiff Bases: a New Class of Fire Retardant

Gaëlle Fontaine, Anil Naik, Séverine Bellayer, Serge Bourbigot

R2Fire group/UMET – UMR CNRS 8207, Ecole Nationale Supérieure de Chimie de Lille (ENSCL), Avenue Dimitri Mendeleïev – Bât. C7a, CS 90108, 59652 Villeneuve d'Ascq Cedex, France.

Schiff bases, alone or chelated by metals, are used in many applications like catalysis, dyes, and corrosion. In 2009¹, we introduced those molecules as a new class of flame retardant. Copper complexes of N,N'-(bis salicylidene)ethylenediamine exhibit numerous advantages; i.e., they are easily synthesized with a very high yield (CC, Figure 1) and they are cheap.

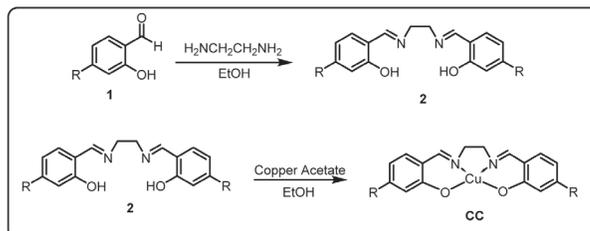


Figure 1: Synthesis route of salen copper complexes

These copper complexes CC and their corresponding salen 2 were introduced in TPU and their abilities as fire retardants were demonstrated at a loading as low as 10% -wt.

Since then, we have developed and synthesized different salens (Figure 2) in order to show their efficiency in polymers. They have been incorporated in several thermoplastics at different loadings and evaluated as fire retardants. Our recent results will be presented in this session. The mechanism of action of our salens has also been investigated and will be fully discussed in the session, revealing why they are efficient to make flame retarded polymers.

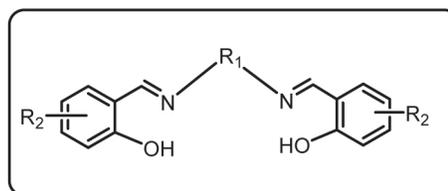


Figure 2 : General formula of salen

¹Fontaine, G.; Turf, T.; Bourbigot, S., Fire and Polymers V, Chapter 20, ACS Symposium, 2009, 1013, 329.

9:00

Thermal Decomposition and Flame Retardancy Mechanism of Polycarbonate- Polydimethylsiloxane Copolymer

Xin Chen, Jinfeng Zhuge, Yuqi Li, Paul Sybert, Wilson Cheung

SABIC Innovative Plastics, Exton, PA 19341. xin.chen@sabic-ip.com.

In recent years, siloxane-based flame retardants drew much attention and are used increasingly to improve polymers' flame retardancy, especially for polycarbonate. Siloxane-based flame retardants can offer high heat resistance, less smoke, and compliance with non-halogen regulations. It is believed that silicone FR containing siloxane units are effective flame-retardants for PC materials because of their rapid movement to the surface of the PC material to form the flame-resistant char barrier during combustion. They also promote cross-linking reactions to form a char barrier consisting of condensed aromatic compounds and siloxane units during combustion.

Polycarbonate (PC)-polydimethylsiloxane (PDMS) copolymers bring good processing compatibility along with excellent mechanical properties. In this session, we will present a fundamental study to understand the thermal decomposition and a flame retardancy mechanism of PC-PDMS copolymers. The effect of PDMS distribution in the copolymer matrix on the thermal

decomposition behavior will be discussed. The PC-PDMS copolymer, FR formulation can further improve the flame performance compared to the PC/PDMS blend system. It was observed that effective synergism between the PC-PDMS copolymer and the P-based FR agent improves the flame performance in PC, and the FR mechanism is dominant in solid-phase action. Not only is the char formation facilitated, but also the intumescent char gets reinforced to better insulate heat and oxygen transfer in combustion.

9:30

How Thiol-Ene Networks Burn: Recent Results on Their Thermal Stability and Flammability

Sergei Nazarenko, Charles Manzi-Nshuti

School of Polymers and High Performance Materials, the University of Southern Mississippi, Hattiesburg, MS 39406. sergei.nazarenko@usm.edu.

UV-cured polymeric materials are used in numerous industrial applications most often as adhesives, coatings, wood products, optical fibers, and inks. The field of photocurable polymers is rapidly growing and expanding into new applications. A majority of commercially used UV-cured materials are acrylates and methacrylates. Recently, photocurable thiol-ene networks gained considerable attention due to the fact that curing reaction in these systems proceeds via unique radical mediated step growth mechanism which defines the uniformity of the network structure, leads to low shrinkage and insensitivity to oxygen inhibition. Because of these advantages, thiol-ene networks can potentially replace acrylate based systems in certain applications. Like with any polymer, the major potential drawback associated with industrial use of thiol-ene network formulations could be their flammability. Despite obvious importance, the information on flammability of thiol-ene systems practically does not exist. The purpose of this work was to explore the flammability of basic thiol-ene systems in order to establish the fundamental structure-property relationships in this field, thus setting up a baseline for further material development and fire retardant modification strategy. An important part of this study was elucidating the burning behavior in situ, which was accomplished by quenching specimens at various stages of the cone test into liquid nitrogen and then investigating the cross-sections by OM, SEM, and SEM/EDX to reveal the morphology and chemical composition of the pyrolysis zone. This session will summarize our recent experimental results on thermal stability and fire retardant behavior of basic thiol-ene networks and discuss ways to control and modify their flammability.

10:00 – COFFEE BREAK

Chairperson: Tim Reilly

10:30

Recent Advances in Fire Retardancy of EVA

S. Bourbigot, C. Hoffendahl, G. Fontaine, S. Duquesne

R2Fire group/UMET – UMR CNRS 8207, Ecole Nationale Supérieure de Chimie de Lille (ENSCL), Avenue Dimitri Mendeleïev – Bât. C7a, CS 90108, 59652 Villeneuve d'Ascq Cedex, France.

EVA (Ethylene-Vinyl Acetate copolymer) are used in a plethora of applications: transportation (aircraft, railway and automotive), E&E, etc. Many of them are directly concerned with fire regulations and the inherent flammability of EVA can be the source of fire hazards.

Aluminum trihydroxide (ATH) is usually incorporated at content around 50–60 wt.% to achieve a satisfactory degree of flame retardancy. In order to decrease the loading while maintaining the other properties, we have developed mixtures of additives. The combination of melamine phosphate (MP) and ATH at 130 phr total loading provides high performance in EVA: LOI jumps from 33 (EVM/ATH) to 38 vol.% (EVM/ATH-MP) associated with significant smoke reduction. Mass loss calorimetry (MLC) coupled with quantitative Fourier Transform InfraRed (FTIR) spectrometry reveals that the peak of heat release rate (pHRR) is not significantly decreased using MP but an additional second

HRR peak does not appear with MP. It is noteworthy acetic acid evolves before the ignition of the two materials (deacetylation of EVA) and the shorter time to ignition (TTI) can be explained by the release of ammonia from MP. In the condensed phase, a physical barrier is formed during combustion, protecting the material against external heat (formation of alumina coming from the dehydration of ATH). The presence of MP leads to the formation of aluminum phosphate in the condensed phase improving stability and insulative properties of the char layer. The mechanism of action involving ATH/MP in EVA will be fully discussed in this session. Based on this approach, other combinations like melamine borate (MB) and ATH will be also examined.

11:00

Fire Retardancy of Polyurea

Charles A. Wilkie

Department of Chemistry and Fire Retardant Research Facility, Marquette University, PO Box 1881, Milwaukee, WI 53201, Phone: 414-288-7239, Fax: 414-288-7066. charles.wilkie@marquette.edu.

Over the past several years, this laboratory has investigated several putative fire retardants for polyurea. In this session, there will be a report of some of the efficacious materials and a comparison with the commonly used intumescent coatings.



Session 6: Instrumentation

11:30

Development of Pyrolysis Models for Simulation of Fire Growth on Polymeric Materials

Stanislav I. Stoliarov

Department of Fire Protection Engineering, University of Maryland, College Park, MD 20742. stolia@umd.edu.

A quantitative understanding of the processes that occur in the condensed phase of burning materials is critical for the prediction of ignition and growth of fires. A number of models have been developed to simulate these condensed phase processes. The main issue that remains to be resolved is the determination of parameters to be input into these models, which are formulated in terms of fundamental physical and chemical properties.

This session will present a systematic methodology for the development of burning models for polymeric and composite materials. This methodology employs thermogravimetric analysis and differential scanning calorimetry to obtain kinetics and thermodynamics of the thermal decomposition and combines these measurements with controlled atmosphere gasification experiments including non-contact spatially resolved thermometry to parameterize heat transport inside the pyrolyzing solids. It will be demonstrated that the material burning models constructed on the basis of these experiments produce accurate predictions of fire growth.

12:00

Development of a Finite Element Model for Predicting the Burning of Materials

Morgan Bruns

National Institute of Standards and Technology, Gaithersburg, MD. morgan.brunsnist.gov.

A material's flammability depends upon a number of coupled physical processes such as thermal degradation chemistry, heat transfer, and the mass transport of combustible gases. While bench-scale tests like cone calorimetry make it possible to screen novel flammability reduction technologies, more thorough evaluation requires expensive full-scale tests. One promising approach for reducing the need for both bench- and full-scale testing is the development of computational models for simulating the

burning of materials. Several models for doing this have been developed in recent years. These models all rely upon a finite difference or finite volume approximation of the governing equations. These methods are easy to implement for simple geometries, but a finite element approximation is more appropriate for the complex geometries found in real commercial products.

In this session, a finite element model for material burning is introduced. The resultant code solves a single energy equation as well as conservation of species equations for multiple gas and solid phase components. Gas convection is modeled by Darcy's Law for porous media flow. The code is verified for 3d heat transfer in a sphere. Validation is performed for 1d thermoplastic gasification scenarios. As a demonstration of a more practical scenario, predictions are made for 2d flexible polyurethane foam smoldering.

12:30

Evaluating Activity of Flame Retardants in Gas Phase

Julien Fage, Shuyu Liang, Sabyasachi Gaan

Chemistry Group, Advanced Fibers, Empa Swiss Federal Laboratories for Materials Science and Technology, Switzerland. sabyasachi.gaan@empa.ch.

There is growing interest in academic and industrial communities to develop flame retardant systems that are active in gas phase. It is important to understand the thermal decomposition process and gas phase activity of the flame retardants. In the literature one can find use of several analytical techniques such as thermogravimetric analysis-mass spectrometry (TGA-MS), TGA- Fourier transformed infrared spectroscopy (FTIR), pyrolysis-gas chromatography-mass spectrometry (Py-GC)-MS, pyrolysis combustion flow calorimetry (PCFC), molecular beam mass spectrometry (MBMS), optical chemiluminescence spectroscopy, laser induced fluorescence spectroscopy, etc., for the detection of volatile thermal decomposition products and active species responsible for gas phase flame inhibition. In this session we will briefly review these techniques. Additionally, we will also present our recent work on the thermal decomposition of dimethyl methyl phosphonate (DMMP) probed by vacuum ultraviolet (VUV) synchrotron radiation and imaging photoelectron photoion coincidence (iPEPICO) spectroscopy. Based on analytical data and chemical quantum calculations we have identified two predominant decomposition pathways of DMMP leading to the formation of active phosphoryl species.

1:00 – 2:00 LUNCH

Chairperson: Sergei Levchik

2:00

Synthesis of Phosphonated Oligomers and Layer by Layer Assembly for Flame Retardant applications

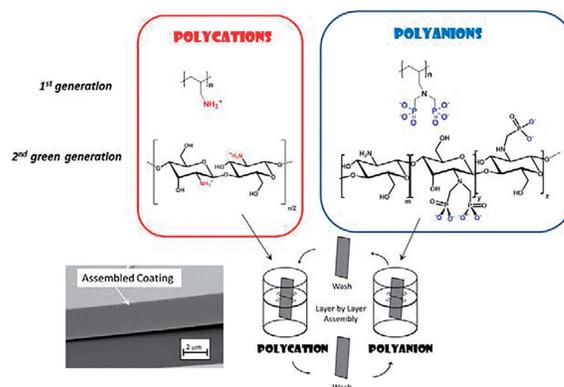
Claire Negrell^{1*}, Federico Carosio², Giovanni Camino², and Ghislain David¹

¹Institut Charles Gerhardt UMR 5253, IAM, 8 Rue de l'école normale, 34296 MONTPELLIER cedex 5, France

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The work focuses on the synthesis and layer by layer assembly of oligoamines and phosphonated oligoamine. To this aim, the synthesis of 2 generations of oligoamines and the phosphonated form (Scheme 1) have been done in aqueous media: the first generation has a vinylic backbone and the second one was a green origin based on a chitosan structure. Firstly, radical polymerization of acid salt of allylamine was performed¹ and characterized by size exclusion chromatography. Phosphorus-containing oligoallyl- amines had a number-average molar mass between 4500 to 20,000 g.mol⁻¹. Secondly, native chitosan was depolymerized via microwaves to obtain low molar masses and post-functionalized via Kabachniks-Fields reaction following to phosphonate hydrolysis. Multilayered films were prepared by the dipping method in a solution of polyanion then a solution of polycation

(Scheme 1). Then, the growth of the assemblies (between 5 to 20 bilayers) on silicon wafers was evaluated by FT-IR spectroscopy and microscopy. Furthermore, thermogravimetric analyses of the LbL assembled polymers showed both high thermal and thermo-oxidative stability. Lastly, the flame retardancy tests² were successfully made on different substrates (cotton, PET or PU foams³) and the influence of nature and molecular weight of oligomers were compared in term of ignifugation efficiency.



Scheme 1: Schematic representation of the layer by layer assembly of Oligoamine and Phosphonated Oligoamine

[1] C. Negrell-Guirao, F. Carosio, B. Boutevin, H. Cottet, C. Loubat, *J. Pol. Sci. Part B : Pol. Phys.* **2013**, *57*, 1244-1251

[2] F. Carosio, C. Negrell-Guirao, A. Di Blasio, J. Alonghi, G. David, G. Camino, *Carbohydrate Polymers*, **2015**, *115*, 752-759

[3] F. Carosio, C. Negrell,

2:30

Development of a Test Method to Determine the Propensity of Building Materials to Smolder

Janet Murrell¹ and Frederick P. Schall²

¹Exova Warringtonfire. janet.murrell@exova.com.

²Deatak Instruments. fred.schall@deatak.com.

The harmonized European test method and classification system has been in place now for over 10 years. Several years ago, following a series of fires where there was re-ignition of building materials and subsequent secondary fire damage even after the fire brigade had extinguished the original fire, it was requested by Germany that this phenomenon should be assessed and all building products labeled accordingly.

This session will discuss the phenomenon of smoldering and smoldering fire propagation in construction products and the development of the new European test method. Smoldering combustion is a process that, after the initiation phase, moves progressively as long as enough organic material is present, enough oxidizer reaches the reaction front and no substantial heat loss occurs. Numerous studies on this process describe and capture the basic conditions and propagation behavior of this sensitive process for various products. Its repeatability is strongly dependent on constant ambient and material conditions which should be defined by any test method.

The method was required to be able to distinguish materials in an objective manner according to their smoldering behavior. During the development of the method different existing methods were explored, different heat sources were considered and many different materials were assessed, with some surprising results. The effect of the addition of fire retardants on the smoldering process will also be addressed.

3:00

Conference Wrap-up

Conference Director: Chuck Wilkie

Flame Conference At-A-Glance

SUNDAY	MONDAY		
7:00-8:00 BREAKFAST	7:00-8:00 BREAKFAST	11:45 – 12:00 Comprehensive Evaluation of Unreacted Flame Retardants in Printed Circuit Boards <i>Feng Yang and Gordon L. Nelson</i>	4:30 – 5:00 Nonformaldehyde Flame Retardant Finishing of 65/35 Nomex/ Cotton Blend Fabric for Protective Clothing <i>Charles Q. Yang and Qin Chen</i>
<p>8:30-5:30 Short Course</p> <p>Course Director</p> <p>Charles Wilkie Marquette University</p> <p>The Course Instructors</p> <p>Kelvin K. Shen Rio Tinto Minerals</p> <p>Sergei Levchik Product Development Manager ICL-IP America Ardsley, NY</p> <p>Matthew Blais Fire Technology Department Southwest Research Institute (SwRI) San Antonio, TX</p>	8:00-8:15 Introduction <i>Charles Wilkie</i>	12:00 – 12:15 The 2015 BCC Research Flame Retardant Report <i>Marcanne Green</i> <i>BCC Research</i>	5:00 – 5:30 Water-Soluble Polyelectrolyte Complexes and Layer-by-Layer Assemblies as Environmentally-Benign Flame Retardant Nanocoatings <i>Jaime C. Grunlan</i>
	SESSION 1: Commercial Products Chairperson: Antenneh Worku	12:15 – 12:45 Towards an Improved Bench-scale Smoldering Scenario for Upholstered Furniture <i>Mauro Zammarrano, William M. Pitts, Szabolcs Matko, Douglas M. Fox, Rick D. Davis</i>	5:30 – 6:00 Observing Smoldering-to-Flaming Transition on Foam/Fabric Assemblies <i>Stanislav I. Stolarov, Alexander B. Morgan, Sergei Levchik</i>
	8:15 – 8:45 Comparative Burn of Flat Panel Televisions from United States, Mexican and Brazilian Markets <i>Dr. Matthew S. Blais</i>	12:45 – 2:00 LUNCH	6:00-6:30
	8:45 – 9:15 Fire Hazards of Lithium Ion <i>Richard N. Walters, Richard E. Lyon, Sean Crowley and James G. Quintiere</i>	SESSION 2: Foams and Fabrics Chairperson: Hongdian Lu	Environmental Friendly Flame Resistant Coatings for Soft Furnishing <i>Yeon Seok Kim, Yu-Chin Li, You-Hao Yang, John Shield, and Rick Davis*</i>
	9:15 – 9:45 Upholstered Furniture Fire Safety: Recent Findings and Regulations <i>Marcelo M. Hirschler</i>	2:00 – 2:30 Preparation of Flame-Retardant and Smoke-Suppressing Expanded Polystyrene Foams <i>Yuan-Wei Yan, Jian-Qian Huang, Yu-Zhong Wang, Dr. Wang Liao</i>	6:30 – 8:00 RECEPTION
	9:45 – 10:15 Material Selection Influence on the Flammability of Upholstered Furniture: Demonstrating the Effectiveness of Flame Retardants <i>Marshall Moore, Carl Powell, Subramaniam Narayan</i>	2:30 – 3:00 Unconventional Additives to Achieve Ultra-Low Smoke Performance in Polyurethane Foam Insulation <i>Gus Ibay</i>	
	10:15 – 10:45 COFFEE BREAK	3:00 – 3:30 Combination of Gas and Condensed Phase Effect of Phosphorus Flame Retardancy in Polyisocyanurate Foam <i>Hongyu Yang Lei Song, Yuan Hu, Richard K.K. Yuen</i>	
	SESSION 1: Commercial Products (Cont.) Chairperson: John Yao	3:30 – 4:00 COFFEE BREAK	
	10:45 – 11:15 Reformulating Targeted Materials: How This Impacts Aerospace OEMs <i>John N. Harris</i>	SESSION 2: Foams and Fabrics (Cont.) Chairperson: Walid Awad	
	11:15 – 11:45 The Changing Landscape for Flame Retardants: Green Chemistry, Voluntary Environmental Standards, and Public Perception <i>Tim Earl</i>	4:00 – 4:30 Vertical Cone Calorimeter Testing of Polyurethane Foams <i>Mary L. Galaska, Alexander B. Morgan, Kathleen A. Schenck, John G. Stalter</i>	

TUESDAY		
7:00-8:00 BREAKFAST	12:00 – 12:30 Some Findings of Fire Retarding Polymer Nanocomposites <i>De-Yi Wang</i>	4:30 – 5:00 A Highly Thermally Stable Phosphorus Flame Retardant for Semi-aromatic Polyamides <i>Qiang Yao, Kai Huang</i>
SESSION 3: Nanocomposites Chairperson: Chandrasiri Jayakody		
8:00 – 8:30 Thermal Properties and Flammability Performance of Polystyrene/Carbon Nanotube/Zirconium Phosphate Composites <i>Hongdian Lu, Jin Liu, Wei Liu</i>	12:30 – 1:00 Structure-Property Relationships of Polyethylene and Polypropylene Graphene Nanocomposites: Thermo-Mechanical Response and Flame Retardance <i>Kai Yang, Yichen Guo, Maya Endoh, Radha P. Ramasamy, Molly M. Gentleman, Thomas A. Butcher, Miriam H. Rafailovich</i>	5:00 – 5:30 Flame Retardant Properties of Phosphorus Esters Derived from Isosorbide Di(14-hydroxy-12-thiatetradecenoate) <i>Bob A. Howell and Yoseph G. Daniel</i>
8:30 – 9:00 Copolyester–Clay Nanocomposite Additives for Flame Retardant Applications <i>Robert Young, Jeff Galloway, Casey Halsey</i>	1:00 – 2:00 LUNCH	5:30 – 6:00 Phosphorus-Based Flame Retardant Coatings for Polymers and Composites <i>Katherine Williams, Piyanuch Luangtriratana, Baljinder Kandola, John Ebdon, A. Richard Horrocks</i>
	SESSION 4: Phosphorus Chairperson: Yu-Zhong Wang	
9:00 – 9:30 Study on the Flame Retardancy of Sulfonate-containing Polyhedral Oligomeric Silsesquioxane (S-POSS)/Polycarbonate Composites <i>ZiQian Li, Rongjie Yang</i>	2:00 – 2:30 Melamine Poly(metal phosphates) as Flame Retardant in Epoxy Resin: Performance, Mechanisms, Synergy <i>Patrick Müller, Bernhard Schartel</i>	6:00- 7:30 – RECEPTION
9:30 – 10:00 Flame Retardancy of Chemically Modified Lignin as Functional Additive to Epoxy Nanocomposites <i>John A. Howarter, Gamini P. Mendis, Alex N. Bruce, Jeffrey P. Youngblood, Mark A. Dietenberger, Laura Hasburgh</i>	2:30 – 3:00 The Use of Oligomeric Phosphonate to add Fire Protection to Sustainable Polyurethane Foam <i>Tim Reilly</i>	
10:00 – 10:30 COFFEE BREAK	3:00 – 3:30 Novel Phosphorus Containing Flame Retardants for Engineering Plastics <i>Manfred Döring</i>	
SESSION 3: Nanocomposites (Cont.) Chairperson: Alex Morgan		
10:30 – 11:00 Improving Fire Safety of Polypropylene/Carbon Fiber Composites by Adding Nanosized Carbon Materials <i>Jiang Gong, Hongfan Yang, Xin Wen, Tao Tang</i>	3:30 – 4:00 COFFEE BREAK	
	SESSION 4: Phosphorus (Cont.) Chairperson: Yuan Hu	
11:00 – 11:30 Self-Assembly of Mesoporous Silica@Ni-Al Layered Double Hydroxide Spheres for Reducing Fire Hazards of Epoxy Resins <i>Shu-Dong Jiang, Lei Song, Yuan Hu</i>	4:00 – 4:30 Synthesis and Flame Retardancy Characterizations of New Bio-Based Phosphorus-Containing Epoxy Thermosets <i>L. Ferry, R. Menard, R. Sonnier, C. Negrell-Guirao, G. David</i>	
11:30 – 12:00 Micro-Scale Study on the Flammability of Polymers <i>Hsinjin Edwin Yang, Pioneer Scientific Solutions; Frederick P. Schall, Deatak Instruments</i>		

WEDNESDAY		
7:00-8:00 BREAKFAST	10:30 – 11:00 Recent Advances in Fire Retardancy of EVA <i>S. Bourbigot, C. Hoffendahl, G. Fontaine, S. Duquesne</i>	SESSION 6: Instrumentation (Cont.) Chairperson: Sergei Levchik
SESSION 5: New Flame Retardants and Specific Polymers Chairperson: Kelvin Shen		2:00 – 2:30 Synthesis of Phosphonated Oligomers and Layer by Layer Assembly for Flame Retardant applications <i>Claire Negrell, Federico Carosio, Giovanni Camino and Ghislain David</i>
8:00-8:30 Anti-Flammable Polymers and Cross-Linked Networks: Difunctional and Multifunctional Deoxybenzoin <i>Todd Emrick</i>	11:00 – 11:30 Fire Retardancy of Polyurea <i>Charles A. Wilkie</i>	2:30 – 3:00 Development of a Test Method to Determine the Propensity of Building Materials to Smolder <i>Janet Murrell and Frederick P. Schall</i>
8:30 – 9:00 Salen-Based Schiff Bases: a New Class of Fire Retardant <i>Gaëlle Fontaine, Anil Naik, Séverine Bellayer, Serge Bourbigot</i>	SESSION 6: Instrumentation	3:00 – 4:00 CONFERENCE WRAP-UP
	11:30 – 12:00 Development of Pyrolysis Models for Simulation of Fire Growth on Polymeric Materials <i>Stanislav I. Stolarov</i>	
9:00 – 9:30 Thermal Decomposition and Flame Retardancy Mechanism of Polycarbonate-Polydimethylsiloxane Copolymer <i>Xin Chen, Jinfeng Zhuge, Yuqi Li, Paul Sybert, Wilson Cheung</i>	12:00 – 12:30 Development of a Finite Element Model for Predicting the Burning of Materials <i>Morgan Bruns</i>	
9:30 – 10:00 How Thiol-Ene Networks Burn: Recent Results on Their Thermal Stability and Flammability <i>Sergei Nazarenko, Charles Manzi-Nshuti</i>	12:30 – 1:00 Evaluating Activity of Flame Retardants in Gas Phase <i>Julien Fage, Shuyu Liang, Sabyasachi Gaan</i>	
10:00 – 10:30 COFFEE BREAK	1:00 – 2:00 LUNCH	
SESSION 5: New Flame Retardants and Specific Polymers (Cont.) Chairperson: Tim Reilly		

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Short Course Registration Fee:

\$1200. (\$1000 for Flame Conference registrants also attending the main conference, May 18-20). Includes breakfast, lunch, beverages, and the conference's Opening Reception on Sunday evening. Each attendee will receive a handout containing a copy of the presentation. Attendance for this course is limited and early enrollment is advised.

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