pinfa
Phosphorus, Inorganic & Nitrogen Flame Retardants Association

Your newsletter for non-halogen fire safety solutions n° 163 September 2024

PINFA IN ACTION

Safe and Sustainable Flame Retardants

New infographic shows pinfa's vision of Safe and Sustainable FRs for fire safety, integral to Europe's sustainability. Fire safety is essential to enable society's green and digital transition. Flame retardants have a key role to play in this. To meet tomorrow's challenges they must be sustainable while delivering optimal fire resistance in materials and technologies. To reach these goals, pinfa calls for strict fire safety standards, innovation funding, and greater recognition of the role flame retardants play in eco-design and safety regulations. Through ongoing research and collaboration with regulatory bodies, pinfa aims to ensure that flame retardants continue to deliver fire safety while supporting Europe's sustainability objectives.

Pinfa infographics:
- Why do we need Flame Retardants?
- Tried & Tested: The Safety of Flame Retardants
- Safety by durability
- Safe and Sustainable Flame Retardants for Fire Safety
https://www.pinfa.eu/media-events/brochures-publications/

pinfa-NA regulatory webinar, 23rd October

The evolving and demanding regulatory context for flame retardants, with Shannon Gainey, Huber Advanced Materials. How evolving regulations may impact the formulation of certain polymer additives including flame retardants into various application.

Free webinar: Navigating Global Fire Retardant Compliance Requirements in an Evolving and Stringent Regulatory Landscape. pinfa-NA's 13th L&L (lunch and learn): Wednesday, 23rd October 2024, 11:30am-12:30pm EDT (17h30 -18h30 Brussels). Free.

Registration:
https://us02web.zoom.us/webinar/register/WN_JijXr53tSjeY3eWX2UPMsw

Pinfa session at European Fire Safety Week

pinfa workshop on the importance of flame retardants in modern society, pinfa, 20th November 13h30, Brussels & online.

European Fire Safety Week 2024, Brussels & online, 18-22 November 2024 https://www.europeanfiresafetyalliance.org/european-fire-safety-week/

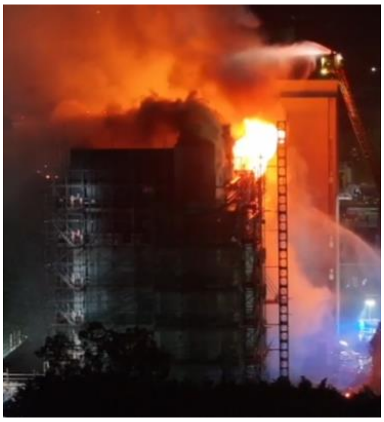
pinfa event: "Fire load and flammable materials in modern buildings: how can flame retardants contribute?", part of /European Fire Safety Week, November 20th 2024 https://www.europeanfiresafetyalliance.org/european-fire-safety-week/edition-2024/registration-form-2024/

Watch online free: flame retardant wood

pinfa-NA's 12th lunch-and-learn webinar, on flame retardant wood, with timber expert Tim Locke, attracted 100 registrants. He explained that PIN chemicals have been used to protect wood from fire since the nineteenth century (e.g. Gay-Lussac ammonium phosphates and borates, 1821). A wide range of proprietary FRs is today available, enabling achievement of specific building code fire performance specifications with different wood species. Most are water born, colourless and are pressure / vacuum impregnated into timber for durable fire protection. Specifications can include non-corrosion (of steel fasteners, nails or screws) and combined FR – preservative action. Challenges are to minimise impacts on the timber's mechanical and aesthetic properties. Wood FRs work by releasing carbon dioxide and water which dilute and quench fire, and by enhancing the natural capacity of wood to produce a fire-protective char layer and by strengthening this layer. FRs applied to wood surface, such as fire protective paints or coatings, including intumescent coatings, are not classified as "FR wood" in US building codes. Tim Locke identified several trends expected to drive demand for wood flame retardants: increasing use of wood in construction for 'green' building objectives; denser urban building so higher residential buildings with higher fire standards; Wildfire Urban Interface (WUI) fire safety requirements; and the development of thermally modified wood (to improve weathering) which also requires FRs for fire safety.

Watch online free, pinfa-NA's 12th L&L (lunch and learn) free webinar. Wednesday, September 25, 2024, one hour. View all pinfa-NA L&L webinars (free) at: https://www.pinfa-na.org/presented-webinars

FIRE SAFETY



Another UK tower block cladding fire

Seven years after the Grenfell fire, another 112-flat building gutted by fire in the UK was known to have unsafe cladding, as well as failures in the London Fire Service and the local council. Fire engulfed the Spectrum tower block, fortunately with no lives lost, but causing injuries and leaving families homeless. Following the Grenfell Tower fire London, which killed over 70 people in June 2017, this was one of 4 600 buildings over 11m high in the UK identified as having non fire-safe cladding. The UK Government says that remedial work has today been completed on less than 30% of these, and started on a further 20%. Media report that work was ongoing to replace non fire-safety compliant Tespa HPL (high pressure laminate) cladding panels on the upper storeys of the Dagenham flats.

BBC News *https://www.bbc.com/news/articles/c07e5ke71kmo*

UK Fire Brigades Union (FBU)
https://www.fbu.org.uk/news/2024/08/26/dagenham-high-rise-fire-exposes-national-scandal-flammable-cladding-says-fbu

Photo BBC News https://www.bbc.com/news/videos/cx29ger1npdo

Thousands of UK flats have unsafe cladding

England and Scotland alone have over 15 000 tall apartment blocks which still have non fire-safe cladding. The UK Government has said that there may be 7 000 buildings for which cladding fire safety remediation is needed which have not yet been declared, in addition to the 4 600 already identified (see above). Surveyors in Scotland suggest that there are 5 500 apartment blocks there with non fire-safe cladding, of which only 140 are in the Government's remediation programme and only one has seen its dangerous cladding removed. This would mean maybe over 100 000 people living in affected homes in the UK, and the problem is much wider with such cladding on buildings worldwide.

"Up to 7,000 unsafe buildings have not applied for cladding safety scheme, minister says", Inside Housing, 12th September 2024
https://www.insidehousing.co.uk/news/up-to-7000-unsafe-buildings-have-not-applied-for-cladding-safety-scheme-minister-says-88533

"Flammable cladding replaced on one of 5,500 Scottish housing blocks", Inside Housing, 12th September 2024
https://www.insidehousing.co.uk/news/flammable-cladding-replaced-on-one-of-5500-scottish-housing-blocks-88525

"List of high-rise façade fires", Wikipedia
https://en.wikipedia.org/wiki/List_of_high-rise_fa%C3%A7ade_fires

Photo Flammable cladding being stripped off Horatia House, Tim Sheerman-Chase, Wikimedia Commons
https://commons.wikimedia.org/wiki/File:Flammable_cladding_being_stripped_off_Horatia_House.jpg

"Systematic dishonesty" on cladding

Grenfell fire inquiry concludes responsibility of Government, cladding companies, the building industry, as well as architects (Studio E), contractors (Rydon, Harley Facades), fire engineers and fire testing (Exova Warrington), the Building Research Establishment (BRE) and the London Fire Brigade. Each and every one of the 72 deaths in the 2017 fire were "avoidable". The 1 700 page final Inquiry report underlines that the non fire-safe combustible cladding and insulation materials used in the 2015-2016 renovation of the tower were the main reason for the rapid and deadly spread of the fire. The Grenfell Inquiry had already (Phase I) established that the fire stared in a Whirlpool Hotpoint fridge-freezer, probably containing non fire-safety treated materials (pinfa Newsletter n°147). The report regrets the "merry-go-round of buck-passing" throughout the Enquiry with neither regulators nor industry accepting responsibility. It underlines the chronic lack of fire safety competence across the construction industry. After fires in the 1990's, UK Governments had been warned about the dangers of combustible cladding and industry fire safety practices, but ignored this. The Inquiry report says that Arconic, manufacturer of Reynobond 55, considered the largest contributor to the fire, "deliberately concealed" the dangers of its product with "deliberate and sustained strategies to manipulate the testing processes, misrepresent data and mislead the market". The report also criticises Celotex and Kingspan. Kingspan's statement on the Inquiry report says that the company acknowledges the "wholly unacceptable historical failings that occurred in part of our UK insulation business" and states that the Kingspan product "made no material difference" to the fire, blaming Arconic's PE ACM (polyethylene aluminium composite material) panels. Arconic state "This product was safe to use as a building material, and legal to sell in the UK … (Arconic) did not conceal information from or mislead any certification body, customer, or the public." The 18 pages of Inquiry recommendations include the establishment of a bofdy of regulated and accredited fire engineers and fire risk assessors, streamlining of fire safety regulation and clarification of information on fire tests to be provided with construction products.

EAFPF (European Association for Passive Fire Protection) published a statement welcoming the Grenfell inquire conclusions, in particular the recommendations to fire safety regulations and responsibilities for their implementation. EAFPF welcomes the report's criticism of small-scale material fire tests and the need for large scale testing of façade systems. EAFPF underlines that the inquiry conclusions are relevant across Europe.

pinfa respects all those who died or still suffer today the consequences of what was an avoidable disaster. pinfa supports the widespread calls that the Grenfell Inquiry's detailed recommendations be examined and implemented, both in the UK and where relevant in other countries.

Grenfell Tower Inquiry final (Phase II) report, 4th September 2024
https://www.grenfelltowerinquiry.org.uk/phase-2-report

"Grenfell Report: Key findings from the inquiry", BBC, 4th September 2024 https://www.bbc.com/news/articles/c049yvrd5qxo

"'Systematic dishonesty' by product manufacturers 'very significant reason' for Grenfell's deadly cladding, inquiry concludes", Inside Housing, 4th September 2024 https://www.insidehousing.co.uk/news/systematic-dishonesty-by-product-manufacturers-very-significant-reason-for-grenfells-deadly-cladding-inquiry-concludes-88334

EAFPF statement, September 2024 https://eapfp.com/eapfp-statement-in-response-to-the-grenfell-tower-public-inquiry-phase-two-final-report/

Photo: Natalie Oxford, WikiCommons https://en.m.wikipedia.org/wiki/File:Grenfell_Tower_fire_%28wider_view%29.jpg

Battery charge fires cause home fire deaths

Fire services say e-bike and scooter charging probably caused several fatal fires. Insurer says battery fires up by nearly 50%. Six people died in a fire, Novi Sad, Serbia, August 2024, possibly caused by an e-scooter charging. A mother and two children died in a fire in a flat, Cambridge, UK, July 2024, which fire services say was probably caused by a charging e-bike. Two people died in a house fire at Teralba, New South Wales, March 2024, caused by a lithium-ion battery. In Tulsa, Washington, a dog gnawing a mobile phone charger caused a fire. The insurance company QBE has collected data showing that UK fire services attended 46% more fires related to lithium-ion batteries in 2023 than the previous year, with almost three battery-related fires per day in the UK. Nearly 30% of these fires involved e-bike batteries. Safety recommendations from fire services and insurers include only using original or reputable brand batteries and chargers, avoiding charging in rooms with soft furnishings, ensuring functioning smoke alarms, not using damaged batteries and unplugging devices once charged.

"UK fire services face 46% increase in fires linked to lithium-ion batteries", QBE Insurer 2024, https://qbeeurope.com/news-and-events/press-releases/uk-fire-services-face-46-increase-in-fires-linked-to-lithium-ion-batteries/

Serbia house fire https://apnews.com/article/fire-serbia-novi-sad-02f5b921d991fded9824fefaebde5d20

Cambridge UK flat fire https://www.bbc.com/news/uk-england-cambridgeshire-66096597

New South Wales house fire https://www.theguardian.com/australia-news/2024/mar/05/lake-macquarie-townhouse-fire-teralba-nsw-first-lithium-ion-battery-deaths

Washington Tulsa dog charger fire https://www.washingtonpost.com/nation/2024/08/07/dog-fire-lithium-ion-battery/

Data on mobility device battery fires

Literature survey finds five published studies on personal mobility device (PMD) fires with 185 burn injuries. The studies from Singapore, Israel, China and France, covering burn injuries from e-bike and e-scooter fires, suggest that fires are often from unattended battery charging. Fires included battery detonations, charger detonations and battery short circuiting. A high proportion of victims are young and male, maybe because this population represents the majority of PMD users. One case concerned an e-scooter confirmed to meet EU standards, showing that certified PMDs may reduce but do not eliminate fire risk.

"Riding Toward Danger: A Scoping Review of Burns Associated With Personal Mobility Devices, Including Electric Bikes (E-Bikes) and Electric Scooters (E-Scooters)", J. Warner-Levy et al., Journal of Burn Care & Research, irae115 https://doi.org/10.1093/jbcr/irae115

CHEMICAL REGULATION

US EPA risk evaluation of TCEP

Official conclusions for the halogenated FR, TCEP, identify potential cancer, nervous system and fertility risks. The EPA concludes that TCEP (tris(2-chloroethyl) phosphate) poses an unreasonable risk of injury to human health and the environment, as defined under TCSA (Toxic Substances Control Act), and so will propose risk management regulatory actions. Unreasonable risk to the public (consumers) was identified in three out of twenty-one applications considered: fabrics and textiles, foams, wood products, as well as risks to workers in other applications including polymers for aerospace, paints and coatings. EPA also found unreasonable risk for aquatic invertebrates, fish and for people eating contaminated fish. EPA already proposed SNURs (Significant New Use Rule, that is notification requirements) for TCEP in 2023 (pinfa Newsletter n°153) and TCEP is already classified as SVHC (Substance of Very High Concern) in Europe.

"Tris(2-chloroethyl) Phosphate (TCEP); Risk Evaluation Under the Toxic Substances Control Act (TSCA)", Federal Register, 26 September 2024 https://www.federalregister.gov/documents/2024/09/26/2024-22061/tris2-chloroethyl-phosphate-tcep-risk-evaluation-under-the-toxic-substances-control-act-tsca-notice

"Risk Evaluation for Tris(2-chloroethyl) Phosphate (TCEP)", US Environmental Protection Agency, September 2024 https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-evaluation-tris2-chloroethyl-phosphate-tcep

NORDIC FIRE SAFETY DAYS 2024

Benefits and risks of flame retardants

pinfa presented flame retardants, why they are used and how they work, at the Nordic Fires Safety Days, Lund, 18-19th June.

This event brought together over 140 fire safety researchers, firefighters, industry and stakeholders, mainly from Nordic countries, with over 70 presentations.

Opening talks by Jakob Andersen, Copenhagen Fire Services, Aldis Larusdottir, Reykjavik Fire Services, and Ann Christin Rognmo Olsen, Norway Fire Services, outlined the challenges today facing fire services: increasing complexity of new buildings, new materials, new energy systems, electrification and batteries, in combination with an ageing population (which makes escape and rescue more difficult) and demands for major incidents and wildfires. At the same time, funding is under pressure. Social aspects are emphasised as important, such as illegal and inappropriate use of business or warehouse properties as rental residencies.

Two sessions addressed fire safety challenges posed by photovoltaic panels in buildings and by batteries, in particular battery energy storage systems (BESS), both domestic scale and commercial / grid storage. Battery systems can be a cause of fire or explosion in case of battery thermal runaway (caused by battery failure or electrical faults), with very rapid fire growth and strong risk of fire spread if the battery storage is within a building. Fire tests of photovoltaic panels show that they can contribute to fires, but are often self-extinguishing (pinfa comment: components, in particular the polymers in which the PV elements are embedded and the polymer back plate are generally flame retarded). Installation should ensure a barrier to prevent fire spread to building materials. Tests show that PV panels installed in walls may release falling debris in case of fire but that their fire resistance is otherwise better than pine cladding.

Challenges for new energy systems and batteries are the need for information, training and on-site signage for firefighters, lack of coherent fire safety regulations and rapid ongoing developments in technologies. Specific challenges are posed by batteries in marine transport, both in cargo and in transported vehicles. A developing fire safety challenge is installation of second-life batteries in houses or other premises, escaping regulatory surveillance.

Several presentations addressed PIN flame retardant applications, including intumescents used to protect steel and other construction materials from heat and fire. Johannes Rex, Lund University, presented cone calorimeter tests of smoke emissions from untreated and PIN flame retardant (ammonium polyphosphate) wood façade materials. The PIN FR-treated wood showed 77 – 92 % lower smoke emissions despite similar mass loss. Further results are pending, including analysis of smoke toxicity.

Questions raised by participants included the durability of fire safety as materials age in buildings, and the lack of data, testing and regulation of such ageing. pinfa studies on materials recycling suggests that PIN FRs are generally durable, with deterioration with ageing impacting mainly the polymer itself (see pinfa Newsletter n°109).

Ellen Synnøve Skilbred, RISE Fire Research, presented analysis of fatal fires in Norway, 2015 – 2020. Nearly 40% of fatal fires were identified as starting in the living room. For around 40% the identified cause was smoking or an open flame. Around 32 % of the deceased were under the influence of alcohol and 21% were under the influence of drugs. Elderly people were overrepresented in the fatal fire statistics. The full report from the project will be published in the autumn of 2024 at https://risefr.com/publications

Mikael Jonsson and Antti Viitanen, Recticel, presented full-scale tests of flat roof insulation, placed underneath 6 m2 of sloping solar panels. Flame retardant PIR foam (polyisocyanurate), 14.2 cm thickness, was compared to mineral wool with the same insulation rating (Comparative fire tests of insulated flat roofs with photovoltaic installations youtube.com). The PIR self-extinguished after about half an hour, showing charring to only 25% of its thickness, whereas the temperature in the mineral wool continued to rise for four hours after the test. The behaviour of the FR PIR foam proved to be not worse in the actual application compared to the mineral wool insulation. At the Recticel stand a brochure in Swedish (PIR myter | Recticel Insulation) "dispels three myths" about PIR, addressing fire safety, cost and environmental impact. Flame retarded PIR does not melt in fire, but chars, so does not release droplets. It can achieve Euroclass B-s1,d0 Reaction to fire classification in an end-use configuration with steeldeck.

pinfa (Chris Thornton) presented benefits and risks of PIN flame retardant use: how they contribute to fire safety and how PIN flame retardants and PIN smoke suppressants can reduce smoke emissions and smoke toxicity, and discussed with participants what research is needed to provide evidence of benefits. pinfa's slides are available on the pinfa website here.

Conference conclusions presented by Anne Dederichs, RiSE Sweden, underlined the increasing complexity of fire safety, the new fire safety challenges of batteries, electrification, green energies and building renovation and the need to ensure durable fire safety (resistance to ageing) and fire safety of bio-based materials. The Nordic Fire Safety Network contributes through education, knowledge sharing and joint projects.

Nordic Fire Safety Days 2024 (NFSD) https://www.ri.se/en/nfsd

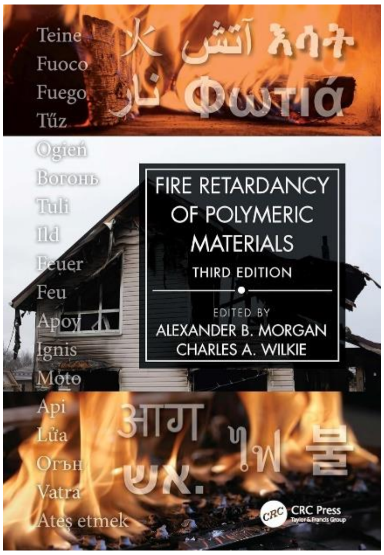
Book of abstracts https://ri.diva-portal.org/smash/get/diva2:1869356/FULLTEXT04.pdf

Nordic Fires Safety Network regular webinars https://www.nfsn.dk/ & https://www.nfsn.dk/events

Pinfa presentation at NFSD 2024 https://www.pinfa.eu/media-events/presentations

The next Nordic Fire Safety Days will take place in 2026.

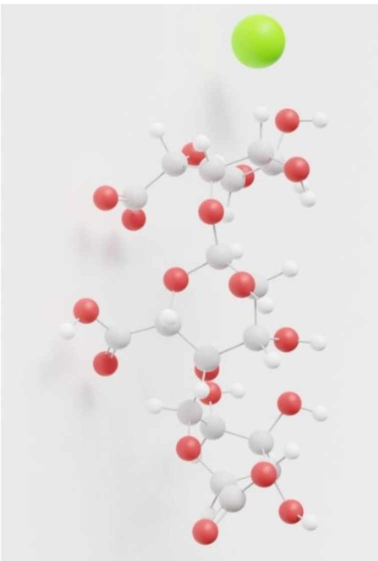
REFERENCE INFORMATION ON FLAME RETARDANTS



3rd edition of FR Polymer Materials book

This encyclopaedic reference on flame retardants is now updated with 775 pages by "the" leading experts. The book covers why flame retardants are needed in today's society, FR and fire chemistries and physics, different types of FR, fire codes, standards and test methods, smoke toxicity, recycling and different FR applications (including fibre reinforced composites, wood & timber, textiles, E&E, wire & cable, building materials, furnishings). The book covers all types of FR, with around 200 dedicated pages for PIN FRs, and around 20 for halogenated FRs. The chapter on chemical regulation of FRs is by pinfa's chairman, Adrian Beard. The previous editions of this key reference book on flame retardants date from 2000 and 2010 and this edition is considerably extended and more complete in scope. The editors, Alex Morgan (University of Dayton) and Charles Wilkie (Marquette University), underline the multidisciplinary approach and comprehensive content of the book, covering all classes of FR (including non-conventional approaches such as chemical cross-linking), physics and chemistry, FR application (e.g. in composites with fibres) as well as regulatory aspects. They underline that flame retardants are needed to respond to ensure safety, with new materials and technologies, to reduce fire risk of both synthetic polymers and composites and bio-based materials, such as wood and timber.

"Fire Retardancy of Polymeric Materials", 3rd edition, ed B Morgan, C. Wilkie, July 2024, CRC Press/Taylor & Francis, 978-1-032-45754-3 price c. 190€ electronic, 270€ paper http://dx.doi.org/10.1201/9781003380689



Flame retardants without flame retardants?

Book chapter looks at metal and organic compounds which generate char or cross-linking in fire … so in fact: PIN FRs! The chapter on non-conventional approaches in the FR Polymers Handbook (see above) considers three PIN flame retardancy approaches. It proposes metal ions which can promote char formation, which is the mechanism used by many mineral PIN FRs and synergists today. Also discussed are metal ions delivered in organic structures, which can also contribute to char formation, covering calcium, aluminium, copper, zinc, barium, zirconium and other metals, with the example of inclusion in natural alginate. Organic compounds which can contribute to polymer cross-linking (by hydrogen bonding, stacking, end-group capture) or polymer rearrangement-based char formation during combustion are discussed, including phenylacetylene, phenylmaleimide, phenylates, deoxybensoins, and N-containing organic compounds: azobenzenes, aromatic Schiff bases, triazoles. Combination of these approaches with conventional PIN FRs is discussed.

"Flame retardants without conventional flame-retardant elements" chapter 15 (22 pages) in Fire Retardancy of Polymeric Materials, 3rd edition, B-W. Liu & Y-Z. Wang 2024 http://dx.doi.org/10.1201/9781003380689-15

New fire safety needs and approaches

Concluding book chapter identifies new fire risk scenarios and today's key challenges for flame retardants and for fire testing. Alex Morgan, editor of the 3rd Fire Retardancy of Polymer Materials handbook (see above) underlines electric transportation (batteries, increasing polymer use in vehicle structures), aviation, changing power systems (DC in renewable energies), wildland urban interface (with increasing wildfires) and additive manufacturing. Key challenges for flame retardant design are identified as the push towards reactive and polymeric FRs (to reduce possible losses from materials, and so reduce exposure and chemical risk), end-of-life compatibility (waste-to-energy and recycling) and cost-effectiveness. There is a need to develop small-scale test methods (rapid, economic) which show good correlation to large-scale fire tests, and so better reflect real fire scenarios. Testing needs to evolve to take into account the new fire safety challenges identified.

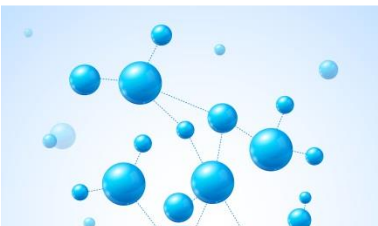
Infographic: Fire Adapted Communities, NFPA (US National Fire Protection Association), https://commons.wikimedia.org/wiki/File:Fire_Adapted_Communities_infographic.jpg

"The future of material fire protection – unmet needs, new fire risk scenarios, and new flame retardant approaches", chapter 32 (28 pages) in Fire Retardancy of Polymeric Materials, 3rd edition, A. Morgan 2024 http://dx.doi.org/10.1201/9781003380689-32

Detailed chemical review of polymeric P FRs

Phosphorus is a "vital" and "effective" fire safety element. Its delivery in polymers enables "non-intrusive" flame retardants, meaning compatible with performance materials, recyclable, eco-friendly and potentially bio-based. 25 pages are devoted to chemical diagrams of over 220 phosphorus flame retardants, with indications of chemical synthesis pathways. Applications and fire protection mechanisms are discussed. Other flame retardant developments are summarised, showing that innovation today concerns mainly PIN FRs. Future prospects highlighted include addressing impacts of P-FRs on material performance, recycling, polymeric and oligomeric P-FRs, reaction of P-FRs into epoxies, phosphorus – amine molecules and chemical inclusion of phosphorus into polymers and combination with carbon fibre. The study also notes the long-term possibility to move to bio-sourced phosphorus for PIN FRs.

"Phosphorus-Based Polymeric Flame Retardants – Recent Advances and Perspectives", I. Singh, A. Sivaramakrishna, ChemistrySelect 2024, 9, e202401485, https://doi.org/10.1002/slct.202401485



Review of polymeric PIN flame retardants

Summary of research into integration of PIN (phosphorus, inorganic, nitrogen) fire resistance into polymers. This paper reviews studies reacting PIN compounds into different polymers including polyurethanes, polyamides, polyimides, polyesters, PET (polyethylene terephthalate), PLA (polylactic acid) and epoxies, as well as specific polymers such as polyoaxadiazoles, polybenzoxazines or polysiloxanes. Phosphorus compounds are indicated to be the most widely investigated for reaction into polymer matrices to impact flame retardancy, but also nitrogen, sulphur and silicon compounds, often with cross-linking. Combinations of phosphorus with other PIN compounds and modification of the polymer structure allow optimal fire resistance, with both solid and gas phase effects, whilst minimising loss of mechanical performance. Polymeric PIN systems produced with renewable and bio-based materials are also discussed.

"A survey of recent publications on polymers employing reactive, halogen-free flame-retardant functionalities", B. Stovall & T. Long, Polymer International 2024 http://dx.doi.org/10.1002/pi.6673

Review of nano-scale FR technologies

Engineering of flame retardants at the nano-scale improves effectiveness and can provide new fire safety mechanisms. This review of nearly 130 publications presents nano-engineering of different types of flame retardant. Only PIN FRs are considered. The review summarises developments in nano-delivery of inorganic PIN FRs (metal compounds: aluminium, magnesium, zin, titanium) where nano-engineering improves fire and mechanical performance. Fire protection mechanisms include water release, heat absorption, catalytic reduction of combustible gases and protective layer formation. Carbon-based nanocompounds include carbon nanotubes, graphene and derivates and carbon nanofibres. Nanoclays and a range of phosphorus-containing nano- PIN FRs are discussed, including P-containing nano-polymers, nanoparticles and intumescents and 'hybrids' combining more than one nano- PIN FR as well as surface-modified nanoparticles and innovative new active nanomaterials. Applications discussed include polymers and plastics, textiles, paints and coatings, electronics, construction and automotive. Challenges to industrial roll-out are identified as the need to verify health and safety, regulatory aspects, scale-up to production of homogenous materials and processing (nanoparticles tend to 'clump' rather than disperse).

"Nanostructured flame retardants: An overview", J. Rodrigues, N. Gopal Shimpi, Nano-Structures & Nano-Objects 39 (2024) 101253 https://doi.org/10.1016/j.nanoso.2024.101253

PUBLISHER INFORMATION

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