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A biodegradable and biobased intumescent flame-retardant for polylactic acid textiles and composites

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Summary

Polymeric materials play an important role in our daily life due to their vast application range and several other benefits such as, ease of processing, thermal stability, low cost and adaptable mechanical properties. However, to improve the sustainability of polymers and to reduce carbon footprint, polymers from renewable resources are given much attention due to the developing concern over environmental protection. These renewable materials are progressively used nowadays in many technical applications instead of short-term use products. However, among other applications, flame retardancy of such polymers needs to be improved for technical applications due to potential fire risk they possess and their involvement in our daily life. To overcome this potential risk, various flame-retardant compounds based on conventional and non-conventional approaches such as inorganic FR's, nitrogen-based FR's, halogenated FR's and nanofillers were synthesized. However, most of the conventional FR's are non-biodegradable and if disposed in the landfill, microorganisms in the soil or water cannot degrade them. Hence, they remain in the environment for long time and may find their way not only in the food chain but can also easily attach to any airborne particle and can travel distances and may end-up in freshwater, food products, ecosystems or even can be inhaled by breathing if they are present in the air. Therefore, the goal of this research work is to promote the use of biodegradable and biobased compounds for flame-retardants used in polymeric materials. The most effective method to enhance the flame-retardant behavior of polymers is to build a char layer at the surface of burning material because it reduces the polymer's pyrolysis rate by condensed phase mechanism and bring it below to a level where self-sustained combustion is not possible. It reduces the free escape of volatile compounds that are formed after combustion by locking them in the charred structure and restricts the dripping of molten polymeric materials, which sometimes is a major reason of flame propagation. The system in which this phenomenon is obtained is known as intumescent flame-retardant (IFR) system. However, in conventional IFR systems, the components used are mainly non-biodegradable and obtained from non-biobased resources such as pentaerythritol (PER). PER is a polyol obtained from petrochemicals and has higher water solubility, which makes it not feasible for polymer thermal processing, melt spinning to produce fibers for textile applications and several other engineering applications. Furthermore, it is not a good choice to use non-biodegradable PER in biodegradable materials such as Polylactic acid (PLA). Thus, it is necessary to test biodegradable and biobased flame-retardants to substitute PER in intumescent formulations for biodegradable polymer PLA. In this way, the whole IFR system can be made biodegradable if all of its components are biodegradable. Hence, it is necessary to propose more environmental friendly approach in IFR system. We therefore, in this dissertation, have developed a biobased and biodegradable intumescent flame-retardant for PLA based textiles and composites. The goal of this dissertation is not only to use biodegradable and biobased flame-retardants in polymeric materials but also to measure the effectiveness and efficiency of the developed products by comparing the FR properties with the standard benchmark properties, defined for the targeted products. Therefore, flame-retardancy of PLA composites and PLA textile products developed in this dissertation is tested with ISO standard testing methods. To achieve these goals, additives composition, temperature profiles and processing conditions of PLA/IFR compounds are optimized to obtain the desired functional and mechanical properties. The melt-spinnability of the developed PLA/IFR formulation is up-scaled from lab to pilot-scale by optimizing the spinning process parameters. IFR multifilaments, based on mono-component and bi-component fibers are developed to produce nonwoven FR carpet backing by thermal bonding and needle-punching techniques. A remarkable increase in flame-retardancy (higher limiting oxygen index values and V-0 ratings in UL-94 vertical burning tests) and a significant decrease in heat release rate, total smoke production and effective heat of combustion were observed. The ignitability test showed none of the fabric sample produced from IFR fibers was ignited after 15 (s) of flame exposure and therefore, achieved E and Efl classification, as per EN ISO 11925-2 standard testing method, which certifies that this product can be used commercially for FR floor coverings. Hence, the results in this dissertation confirmed that biodegradable and biobased additives can be used in IFR's to produce PLA based textiles and composites with comparable FR properties to conventional FR's.