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Thermal characterization of polyurethane foams with phase change material

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Abstract

Taking the joint advantages of the thermal insulation capacity of polyurethane foams (PU) and the thermal energy storage capacity of phase change materials (PCMs), it is possible to produce PU composite foams that can be incorporated as a functional layer into buildings components, designed as latent heat thermal energy storage systems (LHTES), that improve the thermal comfort and the energy consumption of buildings. In this work, PU composite foams containing microencapsulated PCMs (mPCMs) were produced by polyol synthesis. The major aim of the present study was to improve the thermal characteristics of PU foams, by incorporating PCMs, taking advantage of their thermal energy storage capacity. The thermal and energy storage properties were evaluated for three different PU composite foams (hard foam without and with melamine and expandable graphite) with the addition of different percentage of mPCMs. The comparative characterization of the energy storage properties of the PU composite foam formulations is measured using a dynamic scan calorimeter and the thermal conductivity using the transient plane heat source method. The addition of flame retardants to the PU foam slightly influenced the latent heat storage capacity of the PU foam with mPCMs and the addition of mPCMs increases the final thermal conductivity.

Keywords: latent heat storage; phase change material; polyurethane foam; thermal conductivity.

1. Introduction

In the last two decades, the European Union (EU) has been working on new and stricter legislation to control the consumption of energy. The building sector is responsible for consuming 40% of the total final energy use of the EU and produces nearly 40% of the total CO_2 emissions [1,2]. This sector, as one of the major energy consumers, generates pollution and consumes natural resources [3,4]. Therefore, it is necessary that the energy consumption of buildings decreases, but without compromising thermal comfort and indoor air quality [5].

In this context, phase change materials (PCMs) appear as a potential solution to increase the thermal efficiency in buildings since they can store more energy, in the latent form, than the typical sensible energy stored by common materials [6-9].

Phase change materials are divided into two main categories: organic and inorganic [10-13]. This classification depends on different properties: thermal, physical, chemical, kinetic, as well as their economic value. These types of materials have been studied during the last 40 years, mainly hydrated salts, paraffin waxes, fatty acids and eutectics mixtures of organic and non-organic compounds.

To enhance the integration and compatibility of PCMs

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into existing and new building solutions, commercial companies base their solutions mainly on microencapsulated PCMs (mPCMs) composed by microscopic polymer capsules with a diameter approximately of 1-20 micrometres [14,15]. The main advantages of mPCMs are: a) easy incorporation into conventional building materials; b) increase of heat transfer area; c) protection against their destruction and loss of properties; d) good control of the volume change during the phase change [15-19]. The incorporation of mPCMs in PU foams to improve the thermal behaviour and to enhance the energy efficiency in the buildings was firstly undertaken and developed in 1990s [20-23]. As many authors present, the main advantage of the PCMs integration into buildings solutions is the high storage density for small temperature range [7,13,24-26]. This storage capacity increases the building thermal inertia, and it is expected to contribute to solving the time mismatch between the energy supply and the consumption.

Hard polyurethane foams (HPU) are widely used as insulation layers incorporated or associated to opaque building envelope solutions for construction, as well as for other applications such as transportation, decoration and appliances, accounting for almost one-third of the polyurethane market [27,28].

These cellular materials are made by reacting polyols with isocyanates with the proper amount of catalysts, additives and blowing agents. In general, preparation of highly cross-linked polyurethane (PU) material requires a reactive polyol that has a relatively high hydroxyl number ranging from 200 to 800 mg KOH/g. The interest in using bio-based polyols, especially natural oil polyols, in the manufacture of PU products has increased significantly in the recent years [29]. In order to increase the substitution level of bio-based polyols, it is often required that bio-based polyols have good compatibility with the conventional petrochemical-based PU systems and consistent composition. Oil extracted from a plant consists mostly of a composition of various fatty acids. The plant, the seeds of growth conditions and the season have an effect on the composition of the oils. Due to the diversity of fatty acids in biological raw materials, the synthesis of well-defined PU systems presents a problem. For these reasons, polyols based on dicarboxylic acids, instead of fatty acids are still in need of evaluation. Bio-based raw materials of dicarboxylic acids are carbohydrates such as cellulose and glucose. Despite the extensive research and commercialization efforts relating to the development of bio-based polyols or “biopolyols” from renewable resources, petroleum-based polyols still dominate the global polyol market.

You et al. [30] studied the influence of mPCMs on the fabrication of PU foams. Results revealed no significant influence in terms of the thermal stability of PU foam and the enthalpy of the foam rise with the increase of the content of mPCMs, above 12 J/g for the foam containing 12.59 wt% mPCMs. You et al. [22] fabricated PU composite foams containing microencapsulated n-alkanes with general polyether and a combination of polyether polyols. Results revealed the enthalpies of the foam rises steadily as the content of microcapsules increased from 6.4 to 25.2 wt% (28 J/g). Sarier and Onder [27] studied two paraffin waxes (*n*-hexadecane and *n*-octadecane) directly incorporated into the PU foams with different ratios. Results revealed that the PCMs enhance the foams thermal energy storage (TES) capacity. Borreguero et al. [31] incorporated different percentages of microcapsules containing Rubitherm® RT27 into PU foams. Borreguero et al. [32] incorporated up to 18 wt% of two different kinds of thermo-regulating microcapsules having different shell material into the HPU foam. The results showed that the type of microcapsules and their content effect the final foam height, which decreased with the content and particle size. And showed a TES capacity similar to those reported in the literature (16 J/g). In the present work, it was observed that the increase of the microcapsules content in the foams decreases the final foam height rise but increases its density and TES capacity.

Most current research focuses on how the percentage of PCMs influences the thermal energy storage capacity of PU composite foams without paying attention to the thermal insulation performance of these formulations with the presence of different flame retardants This paper gives an overview of the experimental work in order to demonstrate the thermal characteristics of three PU composite foams (hard foam without and with melamine and expandable graphite) containing various quantities of mPCMs and compared resourcing to the transient plane heat source method and the dynamic scan calorimeter (DSC). The main aim of this work is to gain new insights on thermal characteristics of PU foams with mPCMs.

2. Experimental

2.1. Materials

Microencapsulated PCM powder purchased from BASF (Ludwigshafen, Germany) was used in this