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Research Paper

Reducing heat loss through the building envelope by using polyurethane foams containing thermoregulating microcapsules

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HIGHLIGHTS

- RPU foams combining energy accumulation and insulation abilities were produced.
- Composite foams contain between 0 and 50 wt% of thermoregulating microcapsules.
- The TES capacity of RPU foam containing 40% of microcapsules was 3.06 kWh/m$^{3.}$
- Melted fraction of PCM inside the foam was dependent on the indoor temperature.
- Thermal conductivity increased with filler addition and the non melted PCM.

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ABSTRACT

The reduction of the heat loss by incorporating microcapsules into rigid polyurethane (RPU) foams was studied. This way, composite foams containing between 0% and 50% by weight of microcapsules were synthesized. Microcapsules named as mSD-(LDPE·EVA-RT27) from low density polyethylene (LDPE) and ethylvinylacetate (EVA) copolymer containing Rubitherm®RT27 paraffin wax manufactured in a semi-industrial plant of spray drying were used. TES capacities of these composites were quantified by micro and macro scale, observing that phase change materials (PCMs) inside the foam were not entirely melted. Microcapsules addition promoted an increase of the incoming heat flux but lower heat losses respect to the foam without microcapsules in the transient state. Besides, the thermal conductivity of the composites increased with the content of microcapsules but this increase was also related to the non entirely melted PCM. A mathematical model was proposed in order to quantify the total amount of PCM melted during the test and it was possible to confirm that a higher temperature of 36 °C is required to reach the total melting of the PCM. It was also found that an amount of 40 wt% of microcapsules is the proper quantity to produce thermoregulating foams which combine the two advantages: energy accumulation and insulation during the transient state. Besides, the latent heat of this composite was higher than those reported in literature for thermoregulating RPU foams using MicroPCMs from melamine–formaldehyde or styrene–divinylbenzene (DVB) copolymer containing n-tetradecane or n-octadecane, respectively. Finally, if these materials are implemented in building envelopes the amount of CO_2 emitted to the atmosphere could be reduced as well as saving energy.

1. Introduction

The energy performance of buildings is a key point to achieve the energy and climate aims of most of European countries. These objectives are defined by the European Directive 2012/27/UE which emphasizes the need of increasing the energy efficiency in order to reduce in a 20% the Union's primary energy consumption by 2020 compared to forecasts [1]. According to the EU directive 2010/31/UE, residential and tertiary sector account for 40% of total energy consumption in the Union [2]. This energy was mainly spent for buildings comfort and this consumption increases day by day with its subsequent contribution to global warming by the carbon dioxide emissions associated with it.

Moreover, Approximately 85% of the existing dwellings were built before 1990 with poor façade and roof insulation [3]. Due to this weakness much energy is wasted when operating auxiliary heating and air conditioning installations. Current retrofitting

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attempts by increasing envelope thickness bring negative consequences like too high airtightness, over-heating, poor ventilation and loss of space due to voluminous retrofit units.

Passive solar design can be an alternative solution for building heating, but solar radiation is a time-dependent energy source with an intermittent and variable character with the peak solar radiation occurring near noon and for an efficient use it needs to be collected, stored, and distributed in the form of heat [4]. There are materials which have these attributes and are known as phase change materials (PCMs). These materials can absorb or release the energy equivalent with their latent heat when the temperature undergoes or overpasses the phase change temperature range of the material [5].

There is a large list of materials that have been used as PCMs, being mainly classified in organic and inorganic. In applications for buildings the organic ones are interesting due to their properties, such as high chemical and thermal stability, lack of segregation, supercooling or corrosion problems and also, an adjustable transition zone [6].

There are three main methods for PCM incorporation into the buildings: (i) direct incorporation, (ii) immersion and (iii) encapsulation. The first two techniques incorporate the PCM directly in building materials [7], what may bring some problems such as the PCM leakage or the interaction with the other construction materials [8].

Therefore, PCMs should be placed inside a container before being incorporated in buildings. The containment should meet the mechanical requirements: thermal and corrosion resistance, act as a barrier to protect the PCM, provide adequate surface for heat transfer and provide easy handling [9].

Microencapsulation of PCMs with polymeric shells stands out as one of the best confinement options for this application since it meets the requirements mentioned above and, additionally, polymers are cheap and have low density and thermal conductivity [10]. The most common microencapsulation techniques described in literature are the chemical methods of interfacial polymerization, emulsion polymerization, in situ polymerization, suspension polymerization and coacervation; and the physical spray-drying technique [11–14].

The above-mentioned chemical methods involve the use of many reagents (surfactants, inhibitors, initiators, monomers, etc.) that can be found in the liquid phase, increasing the process costs due to the waste treatment, and the particle size is really difficult to be controlled [14,15].

On the contrary, spray drying technique minimizes the waste generation and the loss of the raw materials, allowing the manufacture of a homogeneous product with a desired particle size distribution depending on the atomizer design [16,17]. The spray drying technique involves the atomization of a homogeneous liquid stream (solution, suspension or paste) in a drying chamber where the solvent is evaporated and solid particles are obtained [18].

In a previous work, the microencapsulation of a commercial wax, Rubitherm®RT27, using a low density polyethylene (LDPE) and ethylvinylacetate copolymer (EVA) as shell materials was accomplished by the physical technique of spray drying [19]. Operating conditions and the formulation can be found in the European patent EP2119498 (A1) [20].

These microcapsules were added up to a 21 wt% in rigid polyurethane (PU) foams and their effect on the foam properties were compared with those caused by another two microencapsulated PCMs: one with a polystyrene shell and commercial Micronal®DS 5001X from BASF [5]. This study demonstrated that foams incorporating microcapsules of LDPE and EVA-mSD-(LDPE·EVA-RT27)-pre sented similar thermal energy storage capacity to the other but with better mechanical properties. Therefore, in this work these microcapsules were selected for studying the effect on the thermal properties of higher contents of thermoregulating materials (up to a 50 wt%) into RPU foams. The way in which these composites absorb the energy and how large the heat losses are during the transient state when they are used as a building envelope has not been previously described in literature. Besides, a new easy mathematical model based on the apparent heat capacity obtained by differential scanning calorimetric analyses was proposed in order to know the total amount of PCM that was melted at a specific indoor temperature. These composite materials were synthesized by using mSD-(LDPE·EVA-RT27) produced in a Spray-Dryer pilot plant based on the previous studies [19] with 10 kg/h of capacity designed and built in our facilities.

The influence of the microcapsules content on the thermal properties of composite foams was studied.

2. Experimental

2.1. Materials

Polyol used in this work was R-4520 from Repsol YPF S.A. Polymeric methylene diphenyl diisocyanate (PMDI) was supplied by AISMAR S.A. The catalyst used was Tegoamin 33 and the surfactant was Tegostab B8404, both supplied by Evonik Degussa International AG. Deionized water was used as blowing agent. Spherical microcapsules containing Rubitherm®RT27 with a shell from LDPE and EVA-mSD-(LDPE·EVA-RT27)-were obtained following the method described in the Patent EP2119498 [20] in a pilot plant spray drying. Fig. 1 shows these microcapsules which have an average particle size of 10 μm and a latent heat of 98.14 J/g.

2.2. PU foams synthesis

RPU foams were synthesized in a foaming prismatic probe of $20 \times 20 \times 13\ \mathrm{cm}^3$ by weighting first the desired masses of the polyol, silicone, water, amine and mSD-(LDPE·EVA-RT27) and further stirring the mixture during 1 min. Then, the corresponding mass of isocyanate was added to the mixture and the resulting solution was stirred for just 5 s until the moment at which the foam started to grow. Finally, the obtained foams were cured at room temperature. Table 1 shows the foam synthesis recipe without microcapsules.

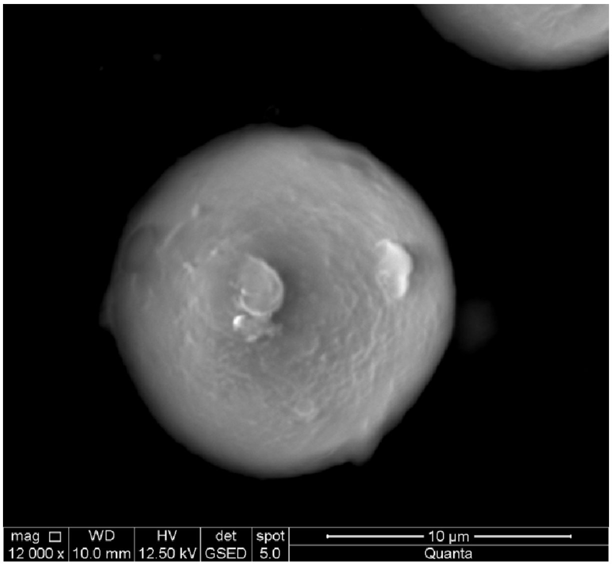

Fig. 1. SEM image of the mSD-(LDPE·EVA-RT27).