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Bubble agitation as a new low-intrusive method to crystallize glass-forming materials

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Abstract

Xylitol is a very promising Phase Change Material (PCM) for long-term thermal energy storage at low to medium temperatures due to its low melting temperature, its high energy density, its high and stable undercooling allowing long-term storage with reduced thermal losses. However, the activation of the energy discharge process (crystallization activation) is difficult and the subsequent crystallization rates (discharge powers) are very low.
To overcome such problems, a simple and efficient technique is proposed. It consists in bubbling undercooled Xylitol using a gas until it crystallizes and the recalescence phase is completed. The mechanisms activating the crystallization are presented in this paper and the bubbling performances are experimentally investigated.

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Keywords: Thermal energy storage ; Phase Change Materials ; Activation of crystallization ; Bubbling.

1. Introduction

Considering the major current energy and economic issues, the development of new PCMs for solar seasonal energy storage, matching the building applications requirements, constitutes a technological challenge. The ideal PCM must have a melting temperature inferior to 100°C, a high energy density (> 100 $kWh.m^{-3}$) for the compactness of the storage system and a large undercooling in order to limit heat losses over the long term storage. It must also be

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cheap, stable, non-toxic and extracted from renewable sources. Currently, many PCM are available in the market for thermal energy storage applications [1,2] but only salt hydrates fit with long-term storage. Indeed, their stable and high undercooling allows reducing thermal losses. Compared to them, SA present several advantages like no separation, no segregation, no corrosion etc. Among SA, Xylitol has a high potential: its melting point is inferior to 95°C which allows using cheap solar collectors; its latent heat is superior to 263 $J.g^{-1}$ and its total energy density is 4-5 times higher than that of water (110-150 kWh.m-3 whereas it is approximately 30 $kWh.m^{-3}$ for water on a seasonal basis). Moreover, Xylitol has a high and very stable undercooling, allowing long-term storage with limited thermal losses and negligible risk of spontaneous discharge. Finally, it has an acceptable cost (< 3 €/kg) and is available in the market. Unfortunately, the discharge process of Xylitol is difficult because of its high viscosity and the subsequent crystallization rates are very low. In this work, different techniques to crystallize Xylitol have been considered. Local cooling fails to trigger nucleation because the activation energy for atoms diffusion and rearrangement at the solid-liquid interface is very high in Xylitol. Seeding allows activating Xylitol crystallization, even in cases with very high undercooled melts. However, the effect of seeding on crystallization is too local and the subsequent crystal growth rates are too low for the application. This technique lead to low heat release rate and too long discharge times. High-power ultrasounds (450 W) also allow crystallizing Xylitol. However, the crystallization rates are also too low for this technique to become appropriate at the storage system scale. Solvents addition does not contribute to accelerate Xylitol crystallization [3]. Mechanical agitation could be a solution to discharge the storage system when necessary and at appropriate speeds. However, this intrusive technique would require a specific reactors design leading to a significant extra-cost.

In this paper, we propose bubbling as a simple and efficient technique to activate Xylitol crystallization and to allow high enough crystal growth rates. As far as we know, the use of a bubbling technique to activate the nucleation of undercooled melts and to accelerate their crystallization rates has never been studied, despite the extensive researches on bubble columns in the last few decades (e.g. recent reviews [1,2]) or the use of bubbling to enhance paraffin heat transfer [4].

Nomenclature

Cp	xylitol specific heat
fs	solid fraction
H	melting enthalpy
L_m	xylitol latent heat
T	temperature of the melt at time t
T0	initial temperature of the melt (also referred as starting/working temperature)
T∞	room temperature, air inlet temperature
T	temperature at the crystal-melt interface (bulk temperature)
V	volume of the melt
PCMs	phase change materials
SA	sugar alcohols
TES	thermal energy storage

2. Experimental techniques

2.1. Samples

Xylitol was purchased from Roquette (batch E089X, purity 98.43%).

2.2. Experimental means

The used liquid/gas reactor is a cylindrical glass vessel of 85 mm of diameter and 105 mm of height, equipped with thermocouples. It is filled with melt Xylitol up to 60 mm height (Fig.1). Air bubbles are generated at the bottom of the vessel by a single tube connected to a pump (tube inner diameter: 3 mm).