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STUDY OF A THERMAL ENERGY STORAGE SYSTEM USING XYLITOL

Summary

Due to the great importance of renewable energies, energy storage is becoming an increasingly relevant technology. Latent heat thermal energy storage (LHTES) is the technology on which this work focuses, and more specifically on xylitol as a phase change material (PCM). Xylitol is a sugar alcohol with promising thermophysical properties, such as high energy density (100kWh/m^3), but it suffers from stable supercooling and low crystallization speed. To overcome these problems, a stirred tank has been used to activate the phase change in xylitol using the seeding and shearing technique. In this work, an experimental campaign has been carried out on this energy storage system to find the optimal operating conditions for xylitol. In addition, an empirical model has been developed to obtain the power curve of the system.

Keywords: Xylitol, latent heat, thermal energy storage system, model, crystallization

Field of application for the findings: Thermal Energy Storage

Addressed audience: Academia

1. Introduction

On the path to decarbonizing society, energy storage is positioned as a necessary tool for the implementation of renewable energies. Among the various storage technologies, this work focuses on thermal energy storage using latent heat. This storage technology uses the latent heat of materials to store heat, using phase change materials (PCMs). There are numerous types of materials that can act as PCMs, such as paraffins or molten salts. However, this work focuses on sugar alcohols, and more specifically on xylitol. Xylitol is a sugar alcohol that melts at around 92°C and has a high energy density (100 kWh/m^3 (del Barrio et al. 2017)). Furthermore, xylitol is neither corrosive nor toxic, and is a cheap material. However, xylitol is not usually considered a phase change material due to the strong supercooling it undergoes, followed by a low crystallization rate. This work will use a storage system consisting of a stirred tank with a coil, very similar to the prototypes already used by the literature (Anish et al. 2021; Navarro et al. 2023). This system allows for easy implementation of the seeding and shearing technique, which activates and accelerates the crystallization of xylitol in the system, a technique already used in the literature (Navarro et al. 2023; Delgado et al. 2021).

2. Methodology

2.1. Prototype characteristics

The system used in this study is an insulated stirred tank with a helical internal coil and jacket, to which a mechanical stirring system has been added. The tank has an internal diameter of 150 mm and a height of 230 mm, insulated outside the jacket with glass wool. The coil is made of copper tubing with an inner diameter of 8 mm, wound into 11 turns (the jacket was not used in these tests), with an estimated effective heat exchange area of 0.12m^2. The system contains 2.5 kg of xylitol as PCM, whose temperature is controlled by a Julabo Corio Cp 1001F thermostatic bath, with Julabo H10 as the heat transfer fluid (HTF). An IKA 60 control mechanical stirrer is used for agitation, a Trigear TC008A2212100 flow meter is used for flow measurement, and four Pt100 probes are used to measure temperature, placed at the inlet and outlet of the coil and to measure the internal temperature of the xylitol. A type T thermocouple to measure the ambient temperature.

2.2. Discharge experiments

The discharge tests were executed as follows: first, the xylitol is melted at 105°C. It is then cooled until a stable test temperature (90, 85, or 80°C) is reached, remaining in a glassy state without changing phase (Puupponen y Seppälä 2018). When a stable temperature is achieved, 12.5 mg of seed mass is added, and stirring begins (100, 500 or 1000 rpm). For the thermal power calculation, an energy balance is performed. In steady state, the thermal losses are obtained, and used for the heat exchanged between the PCM and the heat transfer fluid.

3. Results

3.1. Discharging thermal power

Figure 1 shows several power curves obtained from tests performed according to section 2.2. Tests at different temperatures at 500rpm, and stirring speeds at 85ºC; can be observed over relative time. This method of representing the discharged power is based on the literature (Mehling y Cabeza 2008; König-Haagen et al. 2023).

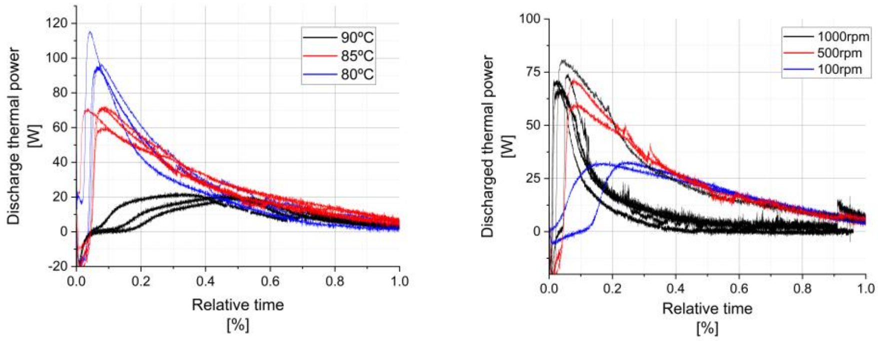

Fig. 1. Instantaneous discharged thermal power. Left) Discharged thermal power at different temperatures and stirring at 500rpm. Right) Discharged thermal power at different stirring velocities, at 85ºC.

Figure 1 shows the thermal performance corresponding to all the test performed. The performance of the tests show an initial decrease in the discharge power towards negative values, followed by a strong increase in power towards the peak, and finally a slow decrease towards the steady state. The negative values at the beginning of the test are mainly due to poor representation of heat losses, as well as a drop in the outlet temperature when agitation begins. The internal temperature of the system increases due to recalescence, also causing an increase in the outlet temperature of the coil, and therefore increasing the thermal power exchanged in the system. This power is mainly determined by the supercooling of the xylitol and the stirring speed.

3.2. System characteristic times

The results presented in Table 1 show that the minimum thermal power is reached at 90°C. It was observed that the stirring speed directly influences the thermal power; although the difference between 1000 rpm and 500 rpm is minimal, the stirring at 100 rpm shows a significant reduction. The decrease in stored energy, shown with an asterisk, is attributed to the thermal degradation of xylitol, whose enthalpy of fusion was reduced from 240 kJ/kg to 200 kJ/kg. When this factor is taken into account, the experimental values agree with the theoretical ones.

Tab 1. System characteristics

Temperature [ºC]	Stirring velocity [rpm]	Maximum power [W]	Maximum power time [s]	Energy discharged [kJ]	Energy discharged time [s]
90	500	22.	18900	455*	44175
80	500	96	1137	466.24*	16583
85	500	69	1709	534	16488
85	1000	70	1320	549	45192
85	100	33	6333	479*	28377

3.3. System modelling

For power curve modelling, the curve_fit function from the Scipy library of the Python programming language was used. Figure 2 shows the three power curves at 85°C, 500 rpm, and 12.5 mg, together with the fitted function. This function corresponds to a lognormal function, with the different parameters A, μ and σ in the text box in the figure. These parameters have been calculated as the average of the individual curve fits. Similarly, the R^2 shown is the average of the R^2 values of the individual fits.

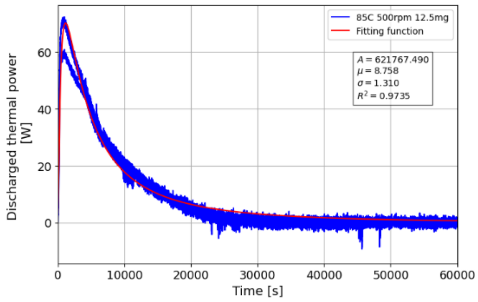

Fig. 2. Discharging thermal power and log normal fitting function

4. Conclusions

This study investigated the thermal performance of a thermal energy storage system using xylitol as a phase change material. It was demonstrated that the seeding and shearing technique not only controls the onset of phase change, but can also control the discharge power of the system to a certain extent. However, it has been observed that the temperature difference between the system and the heat transfer fluid inlet greatly influences the thermal power. Regarding the model, the power has been adjusted to a log-normal function, and a good fit has been observed.

5. References

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