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Molten oxide glass materials for thermal energy storage

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Abstract

Halotechnics, Inc. is developing an energy storage system utilizing a low melting point molten glass as the heat transfer and thermal storage material. This work is supported under a grant from the Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E). Advanced oxide glasses promise a potential breakthrough as a low cost, earth abundant, and stable thermal storage material. The system and new glass material will enable grid scale electricity storage at a fraction of the cost of batteries by integrating the thermal storage with a large heat pump device. Halotechnics is combining its proven expertise in combinatorial chemistry with advanced techniques for handling molten glass to design and build a two-tank thermal energy storage system. This system, operating at a high temperature of 1200 °C and a low temperature of 400 °C, will demonstrate sensible heat thermal energy storage using a uniquely formulated oxide glass. Our molten glass thermal storage material has the potential to significantly reduce thermal storage costs once developed and deployed at commercial scale. Thermal storage at the target temperature can be integrated with existing high temperature gas turbines that significantly increase efficiencies over today's steam turbine technology. This paper describes the development and selection of Halotechnics' molten glass heat transfer fluids with some additional systems considerations.

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Keywords: thermal energy storage; molten glass; electricity storage; oxides

1. Introduction

This paper describes progress on the development of a novel oxide glass material and fluid system for use in a thermal energy storage system. Halotechnics' combinatorial chemistry R&D has identified multiple advanced oxide glasses for use as thermal storage fluid in the range of 400 °C to 1200 °C. The selection criteria for thermal storage media are: (1) Low viscosity over a wide temperature range, (2) High heat capacity, (3) Thermal stability, (4) Low cost, and (5) Low toxicity. Halotechnics has characterized two promising proof of concept materials with suitable thermal properties. This paper will provide a comparison of these materials and discuss their relative feasibility for

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use as thermal storage materials. We will present thermal and physical properties of the materials using measurements taken in our laboratory.

2. Background

Current commercially deployed thermal storage systems are two-tank sensible heat designs using molten salt as the thermal storage media [1]. The most significant drawback of this technology is its relatively high capital cost, where molten salts such as Solar Salt (60% sodium nitrate and 40% potassium nitrate) cannot achieve a large enough difference between hot and cold storage temperatures. Accordingly, there is an industry push by project developers to increase the temperature of storage materials for more efficient, inexpensive operation. As the storage temperature increases, efficiency increases due to higher turbomachinery performance. Additionally, capital cost decreases because more heat can be stored in a given quantity of material. These are the driving forces behind Halotechnics' push for a higher temperature thermal storage material.

Glass is most commonly a mixture of oxides, the most abundant materials in the earth's crust. Oxides are typically what one digs out of a mine – raw ore. Oxide glasses have many compelling characteristics. Firstly, glass exhibits very high thermal stability, where oxides are typical end products of thermal decomposition. As such, metal oxides are stable against further decomposition at very high temperatures, far beyond molten salt. At elevated temperatures, oxides have very low vapor pressure, an important concern in designing thermal systems and storage tanks. Additionally, production of oxide ores occurs worldwide, in quantities of millions of tons annually, leading to very low cost for glass raw materials.

One of the challenges with using molten oxide glass as a heat transfer fluid and thermal energy storage material is its characteristically high viscosity. To meet pumping power requirements Halotechnics' molten glass materials must exhibit viscosity orders of magnitude lower than traditional soda-lime glasses.

3. Methodology

3.1. Experimental Design

Halotechnics owes its thermal materials testing efficacy to methods of high throughput combinatorial chemistry [2]. To that end, Halotechnics has programmed a custom-built software suite for experimental design of glass mixtures. In the standard case of a three-dimensional ternary phase diagram, the user selects three different oxide materials of interest and adjusts the compositions over the region of study. Each oxide component is varied over a set range while selecting the number of divisions within that range. An additional layer of complexity is added by linearly varying a fourth oxide material while keeping the original three components' ratios fixed on the ternary diagram. An example of such a system is depicted below in Figure 1, where each blue dot corresponds to a distinct glass composition. Using this technique, 210 experiments were designed for subsequent synthesis and screening.

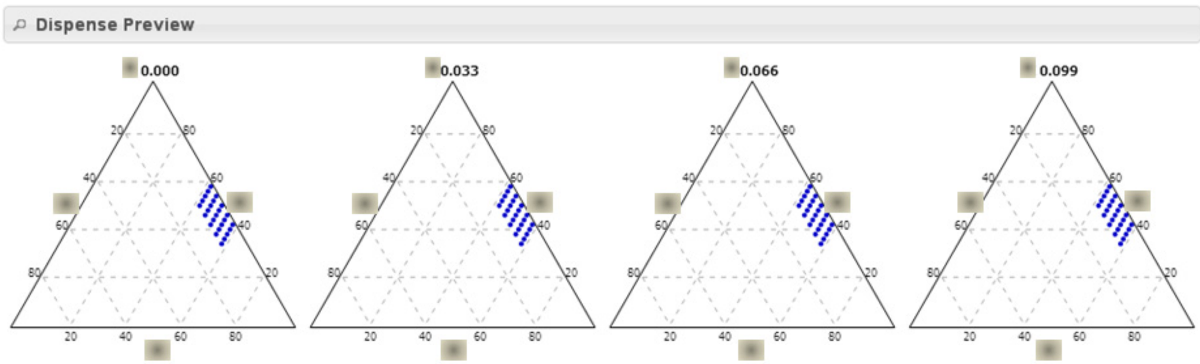

Fig. 1. Sample three-dimensional, four oxide component experimental design.