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Perspectives

Thermal energy storage: challenges and the role of particle technology☆

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ABSTRACT

Thermal energy is at the heart of the whole energy chain providing a main linkage between the primary and secondary energy sources. Thermal energy storage (TES) has a pivotal role to play in the energy chain and hence in future low carbon economy. However, a competitive TES technology requires a number of scientific and technological challenges to be addressed including TES materials, TES components and devices, and integration of TES devices with energy networks and associated dynamic optimization. This paper provides a perspective of TES technology with a focus on TES materials challenges using molten salts based phase change materials for medium and high temperature applications. Two key challenges for the molten salt based TES materials are chemical incompatibility and low thermal conductivity. The use of composite materials provides an avenue to meeting the challenges. Such composite materials consist of a phase change material, a structural supporting material, and a thermal conductivity enhancement material. The properties of the supporting material could determine the dispersion of the thermal conductivity enhancement material in the salt. A right combination of the salt, the structural supporting material, and the thermal conductivity enhancement material could give a hierarchical structure that is able to encapsulate the molten salt and give a substantial enhancement in the thermal conductivity. Understanding of the structure–property relationships for the composite is essential for the formulation design and fabrication of the composite materials. Linking materials properties to the system level performance is recommended as a key future direction of research.

1. Introduction

Energy is the capacity of a physical system to perform work. Energy exists in several forms including electrical, mechanical, chemical, and thermal energy. These forms of energy have different grades with electrical energy being the highest grade and thermal energy the lowest. Direct conversion of electrical form of energy to thermal form of energy has efficiency close to 100%, whereas the efficiency of the reverse process is below approximately 45%. Energy storage refers to a process whereby excess energy is stored in a form that can be converted back to the same form or into a different form when needed. Due to the different forms of energy, many energy storage technologies have been developed. Fig. 1 shows a summary of various energy storage technologies and their development stages. One can see that most energy storage technologies rely on advanced materials developments. This makes powder technology and multiscale phenomena highly relevant disciplines for energy storage research and development.

This paper is concerned about thermal energy storage (TES) and the aims are to provide an overview of the field, to demonstrate the importance of particle technology in the TES particularly the understanding of relationships between properties and structures of TES materials, and to give a future perspective of the area. The paper is structured in the following manner. First challenges in the present energy scenario are outlined in Section 2. The role and

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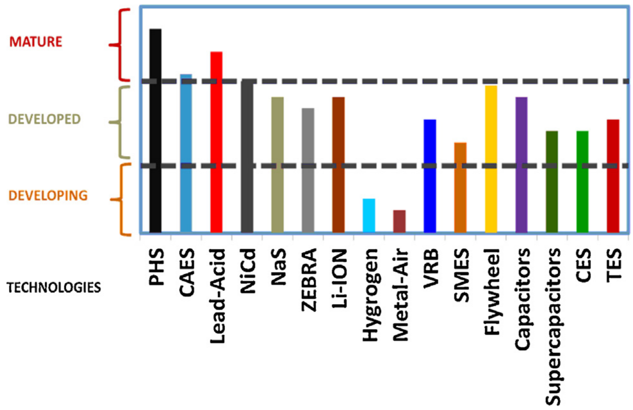

Fig. 1. Energy storage technologies and their development stages (PHS, pumped hydro storage; CAES, compressed air energy storage; NaS, sodium sulphur; VRB, vanadium redox batteries; SMES, superconducting magnetic energy storage; CES, cryogenic energy storage; TES, thermal energy storage).

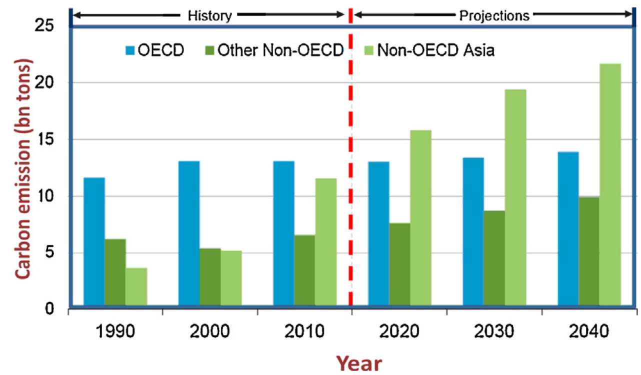

Fig. 3. World energy-related carbon dioxide emissions. (OECD, organization for economic co-operation and development).

importance of thermal energy storage are then highlighted in Section 3, followed by discussions on the TES challenges particularly TES materials challenge in Section 4. Focus is then on microstructured composite TES materials in Section 5 where the role of particle technology is discussed. Finally concluding remarks are given on the future perspectives of thermal energy storage research in Section 6.

2. Challenges in the present energy scenario

Balance of the supply and demand has been and remains an issue in energy supply chain. Traditional energy supply scenario is featured by high proportion of fossil fuels and centralized electricity generation (see Fig. 2). In such a scenario the primary fuels such as coal, oil, and gas are easy to store and transport and hence delivering power on demand. As a result the stocks and distribution of the dispatchable fossil fuels, together with flexible generation facilities, become the most important 'storage' step for balancing the supply and demand in a dynamic manner (Taylor et al., 2012). This fossil fuels based carbon economy has been supporting industrialization and civilization for over a century. However, environmental degradation is growing due to the use of fossil fuels, which has been shown to be one of the main reasons for global warming. Fig. 3 shows global energy-related carbon emission since 1990s and also projections under the assumption that no measures to limit greenhouse gas emissions (Sieminski, 2013).

Of the fossil fuels, oil is a scarce commodity. Linear extrapolation of the rate of growth of oil consumption and the rate of increase of oil reserves suggests the end of oil supply around 2050. Natural gas appears to be an alternative in the medium term and a similar method of prediction suggests the gas supply could continue for 70–100 years (Marbán & Valdés-Solís, 2007). Although significant progress has been made over the last few years in discovering and extracting non-conventional oil and gas (e.g. oil shale and shale gas), only coal is likely to retain its level of availability for a couple of centuries. Due to these reasons, large-scale use of renewable energy sources particularly wind and solar becomes essential. However, the intermittency of wind and solar energy makes delivering reliable power, on demand, a major challenge. Energy storage has the potential to meet the challenge (Taylor, Bolton, Stone, & Upham, 2013). Fig. 4 shows a future scenario with different scales of energy storage capacity.

3. The role and importance of thermal energy storage

Thermal energy storage (TES) stores energy in the form of heat and cold in media termed TES materials. Fig. 5 illustrates a

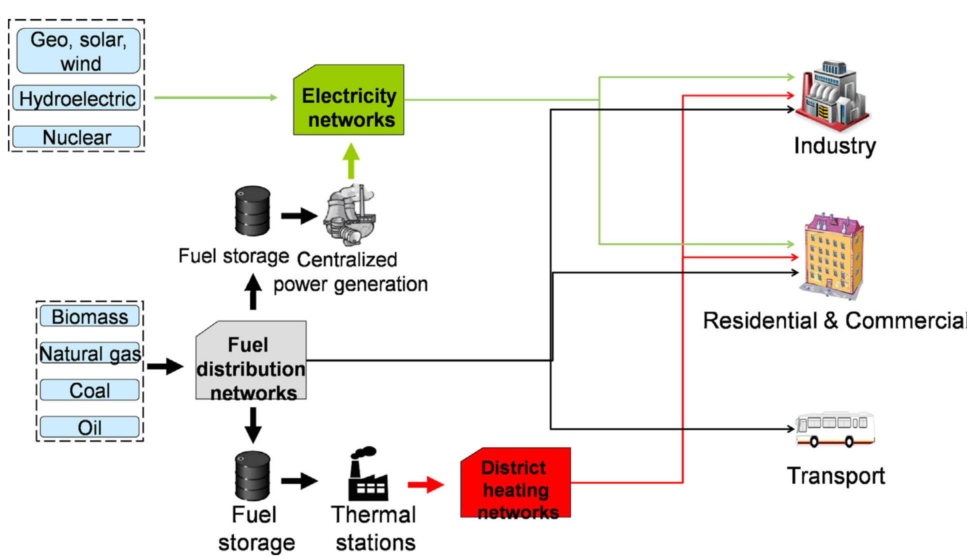

Fig. 2. The current energy scenario.