Progress in Energy and Combustion Science 53 (2016) 1–40

Contents lists available at ScienceDirect

Progress in Energy and Combustion Science

journal homepage: www.elsevier.com/locate/pecs

Thermal energy storage: Recent developments and practical aspects

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A R T I C L E I N F O

Article history:
Received 31 July 2015
Accepted 24 October 2015
Available online 15 December 2015

Keywords:
Thermal energy storage
Sensible
Latent
Thermo-chemical
Encapsulation
Material properties
Improvements
Future R&D

A B S T R A C T

Thermal energy storage (TES) transfers heat to storage media during the charging period, and releases it at a later stage during the discharging step. It can be usefully applied in solar plants, or in industrial processes, such as metallurgical transformations. Sensible, latent and thermo-chemical media store heat in materials which change temperature, phase or chemical composition, respectively. Sensible heat storage is well-documented. Latent heat storage, using phase change materials (PCMs), mainly using liquid–solid transition to store latent heat, allows a more compact, efficient and therefore economical system to operate. Thermo-chemical heat storage (TCS) is still at an early stage of laboratory and pilot research despite its attractive application for long term energy storage.

The present review will assess previous research, while also adding novel treatments of the subject. TES systems are of growing importance within the energy awareness: TES can reduce the LCOE (levelized cost of electricity) of renewable energy processes, with the temperature of the storage medium being the most important parameter. Sensible heat storage is well-documented in literature and applied at large scale, hence limited in the content of the present review paper. Latent heat storage using PCMs is dealt with, specifically towards high temperature applications, where inorganic substances offer a high potential. Finally, the use of energy storage through reversible chemical reactions (thermo-chemical storage, TCS) is assessed. Since PCM and TCS storage media need to be contained in a capsule (sphere, tube, sandwich plates) of appropriate materials, potential containment materials are examined. A heat transfer fluid (HTF) is required to convey the heat from capture, to storage and ultimate re-use. Particle suspensions offer a valid alternative to common HTF, and a preliminary assessment confirms the advantages of the upflow bubbling fluidized bed and demonstrates that particulate suspensions enable major savings in investment and operating costs.

Novel treatments of the TES subject in the review involve the required encapsulation of the latent and chemical storage media, the novel development of powder circulation loops as heat transfer media, the conductivity enhancement of PCMs, the use of lithium salts, among others.

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http://dx.doi.org/10.1016/j.pecs.2015.10.003
0360-1285/

1. Introduction

1.1. Global energy and the required CO_2 reduction

Energy supply is a vital issue, with special concerns of the public regarding the emission of greenhouse gases and the need to reduce the use of fossil fuels [1]. The worldwide economic crisis since 2008 added additional challenges [2], leading worldwide governments to enact new policies and financial incentives in support of renewable energies, enhancing their implementation and development, while simultaneously creating valuable new business opportunities for companies involved in this energy sector [3,4]. One of the hot topics in the energy strategy is the capture and storage of thermal energy as applicable to renewable energy concepts and in waste heat recovery: these advanced energy utilization schemes call for the development and new usage of existing and/or new materials. Based upon the current statistics and predictions of energy consumption, the U.S. Energy Information Administration predicated an increase in the total world energy use from 0.15×10^{12} MWh in 2008 to 0.18×10^{12} MWh in 2020, and to 0.23×10^{12} MWh in 2035 [5]. Since crude oil fuels remain an important source of energy, albeit with depleting traditional reserves but with significant current fracking operations, their prices are expected to remain around 60 US$/barrel for the near future, while 20–40 US$/barrel were valid from 1985 till 2005, but prices of 120–140 US$/barrel are predicted from 2020 onward [5,6].

Because of the use of fossil fuels, current global CO_2 emissions are at 30.6×10^9 tpa of CO_2 (against 28.2×10^9 tpa in 2005). Without effective measures, it is however expected that world energy-related emissions of CO_2 will further increase to 33.5×10^9 tpa in 2015 and 43.2×10^9 tpa in 2035 [5].

The imposed reduction in CO_2 emissions will require a combination of detailed strategies and tactics, including (i) a mix of energy generation technologies; (ii) a reduction in energy usage through the use of incentives, technologies, taxes and quotas; (iii) maximizing CO_2 absorption, through carbon sequestration by both natural means and by technical developments; and (iv) the development of highly-efficient energy capture, storage and re-use methods [3,7]. There is indeed still a considerable scope for improving the energy efficiency. In the short or medium term, waste heat recovery and high temperature thermal energy storage are crucial concepts to implement such solutions, and even current power plants can use high temperature thermal energy storage to improve the energy balance of their operations, since they increase the flexibility and availability of heat and electricity in traditional or sustainable power plants.

The re-use "of low grade heat", typically between ambient temperature and 200 °C, is not widespread since it is a technical and economic challenge to obtain useful exergy and energy from low grade heat. A large amount of low grade heat is available in the process industry, e.g. water from cooling towers with exhaust gas temperatures between 35 °C and 55 °C, and stack exhausts with a broader temperature range, between 30 °C and ~180 °C [8,9]. Highly