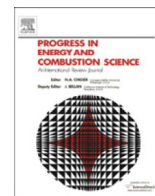




ELSEVIER

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

Huili Zhang^a, Jan Baeyens^b, Gustavo Cáceres^c, Jan Degrève^a, Yongqin Lv^{d,*}^a Bio- & Chemical Reactor Engineering and Safety Section, Department of Chemical Engineering, KU Leuven, 3001 Leuven, Belgium^b European Powder and Process Technology, Park Tremeland 9, 3120 Tremelo, Belgium^c Facultad de Ingeniería y Ciencias, Universidad Adolfo Ibáñez, Diagonal Las Torres, 2640, 7941169 Peñanolén, Santiago, Chile^d Beijing Key Lab of Bioprocess, College of Life Science and Technology, Beijing University of Chemical Technology, Beijing 100029, China

ARTICLE INFO

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

ABSTRACT

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.

© 2015 Elsevier Ltd. All rights reserved.

Contents

1. Introduction	2
1.1. Global energy and the required CO ₂ reduction	2
1.2. Maturity of different energy storage systems and cost effects	3
1.3. Energy storage in general, and thermal energy storage specifically	5
1.4. Heat balances in thermal energy storage	5
1.5. Classifications of thermal energy storage	6
1.5.1. Classification according to temperature range and associated re-use technology	6
1.5.2. Classification according to energy storage mechanism	8
1.5.3. Classification according to the storage concept	8
1.6. Objectives and structure of the paper	8

* Corresponding author. Beijing Key Lab of Bioprocess, College of Life Science and Technology, Beijing University of Chemical Technology, Beijing 100029, China. Tel.: +86 10 64454356; Fax: +86 10 6471 5443.

E-mail address: lvq@mail.buct.edu.cn (Y.Q. Lv).

2.	Sensible heat storage	10
3.	Latent heat storage	10
3.1.	Main characteristics	10
3.2.	PCMs classification	10
3.3.	Moderate or high temperature PCMs	11
3.4.	Specific PCM applications	13
3.4.1.	Latent heat storage with cryogenics	13
3.4.2.	Latent heat storage with steam accumulators	14
3.4.3.	Moderate to high temperature PCMs	16
3.4.4.	The growing importance of lithium salts	16
3.5.	Mechanisms to improve phase change material applications	18
3.5.1.	General principles	18
3.5.2.	Review of applied enhancement methods	19
3.6.	Nanoparticle-encapsulated PCMs	21
3.7.	Cascades of PCM systems	22
4.	Thermo-chemical heat storage	23
4.1.	Principles	23
4.2.	Thermodynamic assessment	23
4.2.1.	Gibbs' free energy and work recovery	23
4.2.2.	Calculation results	24
4.3.	Kinetics from thermogravimetric analysis	24
5.	Containment of LHS and TCS materials	26
5.1.	Preliminary selection concerns and criteria	26
5.1.1.	Pressure upon phase change or chemical reaction	26
5.1.2.	Design of the encapsulation	27
5.1.3.	Preliminary selection criteria	28
5.2.	Relevant properties of E-materials	28
5.2.1.	INCONEL alloy 600 [187]	28
5.2.2.	Incoloy 825 [191]	28
5.2.3.	Extruded tubular ceramics [192–196]	29
5.3.	Experimental design data	29
6.	PCM/TCS integration in TES requires heat carriers	30
6.1.	Introduction	30
6.2.	Powders as novel heat carriers in renewable energy systems	30
6.2.1.	Dense up-flow of particles	32
6.2.2.	Particle loops in SPT and CSP applications	32
6.2.3.	Recent experimental results	32
7.	Conclusion and recommendation for priority research	35
	Acknowledgements	36
	References	36

1. Introduction

1.1. Global energy and the required CO₂ 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 CO₂ emissions are at 30.6×10^9 tpa of CO₂ (against 28.2×10^9 tpa in 2005). Without effective measures, it is however expected that world energy-related emissions of CO₂ will further increase to 33.5×10^9 tpa in 2015 and 43.2×10^9 tpa in 2035 [5].

The imposed reduction in CO₂ 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 CO₂ 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

Download English Version:

<https://daneshyari.com/en/article/241622>

Download Persian Version:

<https://daneshyari.com/article/241622>

[Daneshyari.com](https://daneshyari.com)