Renewable and Sustainable Energy Reviews 52 (2015) 289–307

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

An overview on design methodologies for liquid–solid PCM storage systems

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ARTICLE INFO

Article history:
Received 7 November 2014
Received in revised form
24 May 2015
Accepted 27 July 2015
Available online 13 August 2015

Keywords:
Phase change materials
Design methodologies
Dimensionless correlations
NTU
LMTD
Conduction Transfer Functions
Numerical models

ABSTRACT

Energy storage can facilitate the transition process from the actual energetic model to a model based on renewable energies. A lot of attention has been put in such technology, being the use of phase change materials (PCM) of high interest. However, design methodologies for PCM storage systems are still a limiting factor for its deployment. This paper compiles and structures the most common and promising design methodologies and highlights their usefulness and limitations. These methodologies are classified in six types: (1) empirical correlations and characterizing parameters, (2) dimensional analysis and correlations, (3) effectiveness–NTU, (4) Log Mean Temperature Difference (LMTD), (5) Conduction Transfer Functions (CTF), and (6) numerical models. Dimensionless correlations and effectiveness–NTU are the most common and straight-forward methods as well as the ones that offer more possibilities for general solutions. Empirical correlations and numerical models are problem based and difficult to generalize. On the other hand, the adaptation of LMTD and CTF to PCM systems still requires detailed research.

Contents

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http://dx.doi.org/10.1016/j.rser.2015.07.119
1364-0321/

1. Introduction

In the past decades a lot of attention has been put in energy systems. The unsustainable energetic model and the scarcity of resources, as well as the contribution of fossil fuels to global warming resulted in a growing concern about energy efficiency and renewable sources [1].

One key technology to facilitate the implementation of renewable energies and to enhance energy efficiency is energy storage. It helps to improve energy management as well as to bridge the mismatch between energy production and demand, common in renewable systems [2].

Several technologies are available depending on the kind of energy that needs to be stored. Within them, thermal energy storage (TES) has been rapidly developing in the past years, with especial effort in latent heat storage systems [3,4].

Latent heat takes advantage of solid/liquid phase change in order to store high amounts of energy with small volumes of material. Moreover, the energy is stored at an almost constant temperature, since the phase change process occurs at a very narrow temperature range. Depending on the application, a suitable phase change material (PCM) must be selected.

A lot of effort has been made in the development and testing of different PCM storage systems [5–10]. Heat transfer is usually the main limitation in the design process and, besides, common design methodologies of heat exchangers and building envelopes are not always applicable due to the non-linear behavior of PCM. Thus, new design methods are necessary.

Usually, design methods for PCM systems are based on numerical models developed for each specific application [11]. This process strongly limits the implementation of such systems in real applications, since these tools are only used at research level. However, some straight-forward design methods are available, as well as commercial software that incorporate the capability to simulate PCM systems.

These methodologies are currently scattered in the literature, making their use difficult among architects and engineers and also for researchers to validate and extend them. Therefore, there is a need to compile and structure all this information in order to clearly present the available methodologies and its range of validity, and to identify new research opportunities.

This paper reviews the most common design methodologies, highlighting their limitations and exploring the different approaches available for its adaptation to PCM systems.

2. Requirements and considerations for the design

Many energy systems require of thermal energy storage, either for heat or cold, for a good performance. Up to date, most storage facilities use a single-phase storage material for that purpose. The use of latent heat increases the energy density of the storage with high temperature control close to the melting point. Nevertheless, some problems and requirements must be fulfilled.

2.1. Type of PCM

Several types of PCM have been studied up to date in order to find the most suitable material for each application. In 1983 Abhat [12] provided a useful classification of substances used for thermal energy storage (Fig. 1). The classification was divided in organic and inorganic materials, and included paraffin, fatty acids and hydrated salts, as well as eutectic mixtures. From then on, several authors have compiled PCM candidates and their main properties in order to make the material selection easier [13–16]. In recent years, these classifications have been extended, including new material developments [17,18].

2.2. Temperature and enthalpy

Depending on the application and the desired/available temperature levels and gradients, a phase change material must be selected. The phase change temperature of the PCM must be between the charging/discharging temperatures (or between the source temperature and the demand one) in order to be able to complete a full cycle. Moreover, the temperature gradient will highly influence the heat transfer and therefore the power available.

The phase change enthalpy will determine the energy stored in the material, and therefore the amount of material needed. A high enthalpy is advisable in order to maximize the energy stored per volume unit and to be competitive against sensible storage systems. In addition, high specific heat is also advisable, since the PCM can also work in the sensible range during some periods.

2.3. Compatibility and stability

A suitable combination of PCM-encapsulation material must be used in order to avoid mechanical failure, leakage, degradation and a short life span of the system due to material incompatibility. The selection of a suitable pair is not trivial, and many studies have been published related to this topic [19–21]. As a general guide, problems can appear when using [17]

- Metals in contact with inorganic PCM (corrosion).
- Plastics in contact with organic PCM (stability loss).
- Plastics in contact with organic or inorganic PCM (migration of the PCM).

PCM stability is also a requirement, since the PCM must not change its behavior depending on the thermal cycles undergone. The behavior of many PCM candidates may decay after several cycles; therefore several tests must be done. Although this will not

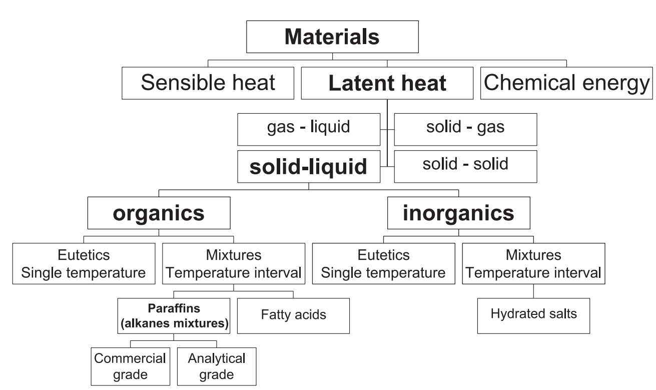

Fig. 1. Classification of energy storage materials [12].