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Applications of solar water heating system with phase change material

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ABSTRACT

The aim of the paper is to provide the review towards the solar water heating system with phase change material. Research questions relating to the solar water heating system using phase change material were analyzed in two sides, i.e., structural characterization and research methodology, followed with the brief introduction of phase change material. The opportunities for further works were identified in technical and economical aspects. The technical opportunities involved in improving characteristics of phase change material for application in solar water heating system, developing novel solar water heating system for integration of system components with phase change material, performing long-term, real-weather and in-situ testing for optimizing operational and structural parameters of novel system, and proposing standardization of novel system for design, manufacture, utilization and marketing. The economical opportunities were presented as in conducting economical analysis to propose cost-effective system and evaluate the feasibility in different locations of the world, and providing subsidies to promote cost-effective system. This study will help identify the potential research gaps for the improvement of the energy efficiency of the solar water heating system and reduce the conventional fossil fuel consumption and carbon emission in the world. This research will also provide the guidance for the domestic and global researchers and engineers working on this area.

Contents

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1. Introduction

Solar water heating (SWH), one of the most popular solar thermal systems, accounts for 80% of the solar thermal market worldwide [1,2]. Over the past few decades, SWH have gained wide applications in the building sector all over the world [3]. However, the systems have been identified with a number of technical problems becoming the barriers to their promotions, e.g., low efficiency in cold climate, high heat losses during night and poor solar harvesting capability, as well as the economic barriers, e.g., high cost in some regions.

Phase change material (PCM) is a kind of latent energy storage material by undergoing an isothermal or near isothermal phase transformation, which has attracted considerable attentions due to the high energy storage density and compactness of the material [4,5]. The study of PCM was pioneered by Telkes and Raymond in the 1940s, and received much interests in the period of late 1970s and early 1980s during the energy crisis when it had been extensively studied for use in different applications especially in solar heating systems due to their distinct operational advantages, e.g., small temperature variation, small size of volume/mass and high energy storage capacity [6,7]. These merits of PCM will potentially resolve the existing barriers of SWH and broaden the application of SWH in global market.

Based on the research background above, the paper will focus on the review of SWH with PCM, followed with the brief introduction of PCM in working principle and classification. The overview works will be analyzed, and the opportunities for further works will be addressed, which will help to improve the solar-thermal efficiency and reduce the cost of the SWH. This study will help to understand the current status of the development of SWH using PCM, develop the potential technical and economical research areas to improve the performance of the solar systems, establish the associated strategies relating to the design, manufacture, optimization and installation of the system and promote the solar thermal global market. The study will therefore contribute to achieving the targets of energy saving and renewable energy utilization, as well as carbon emission reduction in building sector all over the world.

2. PCM used in the SWH system

2.1. Introduction of PCM

Phase change material (PCM), also called latent heat storage material, has high capability to store and release large amount of heat within the constant or a narrow temperature range, which is one of the most attractive functional materials among various heat storage materials [8,9]. The application fields include electronic cooling, waste heat recovery, smart housing, temperature-control greenhouse and textile, telecommunication and microprocessor equipment [10–13]. Most recently, PCM has been widely used in solar energy utilization systems (e.g., SWH).

2.2. Classification of PCM

All kinds of PCM can be classified as in Fig. 1 and described as follows.

PCM can be divided into solid–solid, solid–liquid, solid–gas and liquid–gas types [14]. Of which, the solid–solid and solid–liquid types are most commonly found in the global market. Solid–solid type of PCM are fairly developed functional material, which have the characteristics of no liquid or gas generation, small volume change, small chance of occurrence of sub-cooling, no corrosion, non-toxicity, high heat efficiency and long service time, although they are expensive, have poor thermal conductivity and easy to turn into volatile plastic crystal over the phase change temperature [8,15,16]. The advantages of the solid–liquid type exist in low cost, and the disadvantages include the phenomenon of phase separation and super-cooling, large volume change, easy leakage, and environmental pollution.

Typical solid–solid type includes cross-linked high density polyethylene, layered calcium titanium and polyatomic alcohol [8], and solid–liquid type [4,17] involves three subcategories, i.e., inorganic [18] (e.g., hydrous salt and metal or metal alloys), organic [17,19–23] (e.g., paraffin and fatty acid), and composite [24–26], based on the thermal and chemical properties of the material.

It should be mentioned that due to the solid–liquid type undergoing large volume change during melting and solidification, an encapsulation structure is always selected for the filling of the solid–liquid PCM [27,28]. This structure could contain the material in liquid and solid phases, prevent possible variation in chemical composition by interacting with the environment, increase compatibility with other materials of the storage, increase handiness and provide suitable surface for heat transfer.

2.3. Properties of PCM

The main criterion of selecting the proper PCM for SWH application is the phase change temperature of the material. Other parameters, e.g., values of latent heat and thermal conductivity,

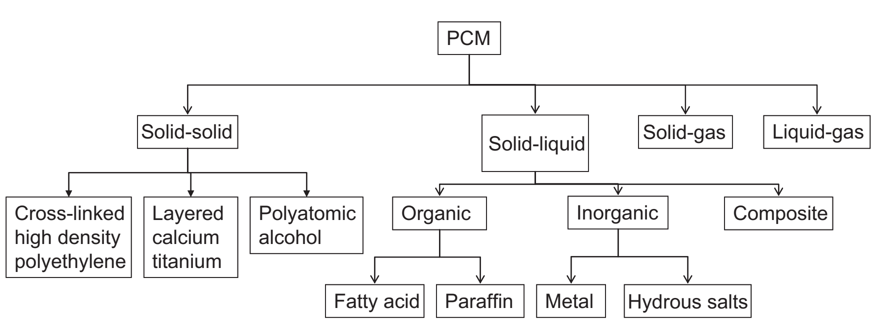

Fig. 1. Classification of PCM.