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Review of the application of phase change material for heating and domestic hot water systems

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ABSTRACT

Heating and domestic hot water (DHW) systems account for 75% of energy consumption in residential, commercial, and industrial sectors. Furthermore, thermal energy storage strongly reduces energy consumption. Storage devices of thermal energy from phase change material (PCM) are essential in solar thermal and waste heat energy technologies that match energy supply to demand and enhance their thermal performance. The storage of PCM thermal energy is more beneficial than sensible energy storage because of its high density of storage energy per unit volume/mass. This review presents previous works on thermal energy storage as applied to DHW and heating systems. PCM has been used in different parts of heating networks and DHW systems, including solar collectors, storage tanks, packed beds, and duct networks. Researchers have also investigated the application of PCM in heating and DHW systems to reduce greenhouse gas emission and electrical power consumption. Hence, PCM thermal energy storage is expected to lower cost and the volumes of heating and DHW systems.

Contents

1. Introduction

Industrial sectors and residential and commercial buildings consume much energy, particularly in space heating and domestic hot water (DHW) systems. The total energy usage of the residential and service sector accounts for 35.3% of total global energy consumption. Of this percentage, 75% is used for space and domestic water heating [1]. In order to significantly reduce this consumption, the thermal energy of phase change material (PCM) is used. This process reduces the mismatch between energy supply and demand and improves the energy efficiency of solar thermal energy technology. PCM thermal energy storage is based on the energy absorbed/generated when a material undergoes a phase change from solid to liquid, liquid to gas, or vice versa. To lower the energy consumption cost of conventional electrical heaters in heating and DHW systems, PCM thermal energy is stored during

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the off-peak load period. This energy is then released during the peak period. Researchers have studied the thermal energy storage with PCMs intensively given their high densities of thermal energy per unit volume/mass and applicability in different engineering fields under wide temperature ranges. Refs. [2–8] comprehensively reviewed different types of PCMs with respect to their characteristics and classifications, Al-Abidi et al. [9] described the application of PCM in air conditioning systems; Rraj and Velraj [10] reviewed PCM use in free cooling technology.

Dutil et al. [11] and Verma et al. [12] reported the mathematical model for PCM; Al-Abidi et al. [13] determined the computational fluid dynamics for PCM; Jegadheeswaran and Pohekar [14] summarized enhancement techniques of heat transfer for PCM application.

In most residential, commercial, and industrial building equipment, such as those for bathing, laundry, and cleaning, the required hot water temperature is approximately 50 °C to 60 °C. This range is considered ideal for PCM melting. With PCM as tank storage material, the maximum temperature of the stored hot water can be controlled and its heat storage capacity can increase [15]. The storage of PCM thermal energy also extends the operation time of renewable energy systems. Furthermore, PCMs are used in heating systems. Most concepts of PCM focus on heating and are viewed either passively or actively [16]. Moreover, PCM has been applied to different components of heating networks and DHW systems, such as solar collectors, storage tanks, packed beds, specific heat exchangers, and ventilation duct networks.

2. PCM incorporation into a solar collector

In this method, PCM is inserted in a solar collector. Fig. 1 shows the different technologies used on flat plate solar collectors. This type of technology is advantageous given that it prevents energy and thermal loss in either pipe or duct networks, reduces initial cost because insulation and storage tank are unnecessary, and saves system space/volume in the system. Several researchers have studied this method as follows.

2.1. Water solar collector

Water is usually used as heat transfer fluid (HTF) to transfer solar energy harvested from the sun, as well as the energy stored by storage-collector technology, to the application. PCM is inserted either into the back of the collector or wrapped around its tube. In extensive studies of this type of technology, researchers generally cover the entire tube below the absorber with PCM. Moreover, PCM typically covers half the permitted tube area. In some cases, the area under the collector tube is covered as well. Some researchers have also used reflectors to absorb additional energy; however, these reflectors act as insulated panels when the PCM thermal storage system is either in operation or is fully charged as indicated in Fig. 1(d).

Khalifa et al. [17] compared the thermal performance of a DHW system with PCM and those of a conventional DHW system. In this study, the solar collector that acts as the PCM thermal storage medium consists of six 80 mm diameter copper pipes that are connected in series and are integrated with a back container of paraffin wax. The performance of the integrated thermal storage-collector device is compared with that of the conventional device in terms of parameters such as the temperature difference across the collector, instantaneous efficiency, heat removal, and overall heat loss coefficient. The results indicated that the temperature difference in the storage-collector is 66% higher than that in the conventional one. Furthermore, the instantaneous efficiency of the

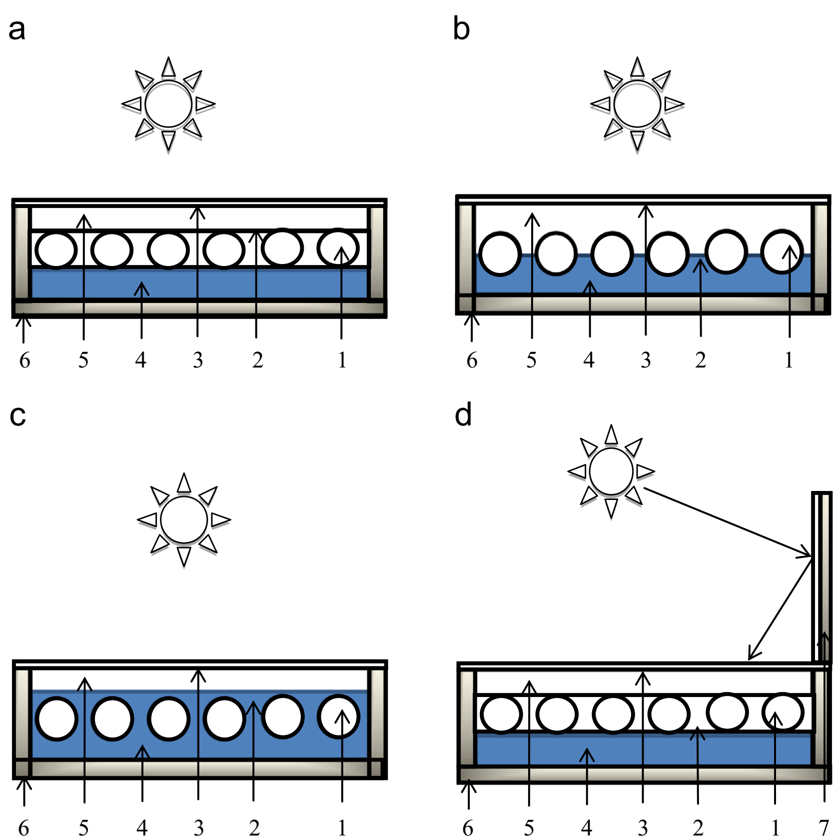

Fig. 1. Schematic of a flat plate solar collector with PCM technologies (a) below tubes, (b) half perimeters of the tubes, (d) immersed tubes, (d) with reflector, (1) tubes, (2) absorber, (3) glass cover, (4) PCM, (5) air layer, (6) insulation, (7) reflector.