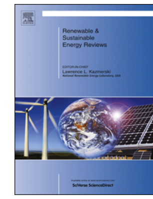
Renewable and Sustainable Energy Reviews 49 (2015) 517–533

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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



Solar domestic hot water systems using latent heat energy storage medium: A review

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ARTICLE INFO

Article history:
Received 18 February 2014
Received in revised form
31 March 2015
Accepted 23 April 2015

Keywords:
Solar domestic hot water
Latent heat storage
Phase change material
Melting
Solidification

ABSTRACT

Solar energy is a clean, abundant and easily accessible form of renewable energy. Its intermittent and dynamic nature makes thermal energy storage (TES) systems highly valuable for many applications. Latent heat storage (LHS) using phase change materials (PCMs) is particularly well suited for solar domestic hot water (SDHW) applications as it offers high storage density and heat transfer at near-constant temperature. This article reviews TES technologies for solar water heating systems with a particular focus on techniques for integrating PCM into these systems. These techniques include integrated PCM storage vessels, integrated PCM solar collectors, and integrated a PCM unit inside the solar hot water circuit. It is found that the integrated PCM storage vessel is the most widely applied technique in SDHW systems using PCMs. The latent heat storage unit configuration and heat transfer mechanisms are further reviewed. Furthermore, this review presents recent findings on the performance comparison between conventional SDHW systems and SDHW systems containing PCMs and the long term performance of SDHW system using PCMs are discussed. This review highlights the need for further research in several areas including performance evaluation of different integration techniques, numerical model for system optimization, and long-term performance of solar domestic hot water systems featuring PCMs.

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http://dx.doi.org/10.1016/j.rser.2015.04.147
1364-0321/

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1. Introduction

The current global reliance on fossil fuels for energy production presents environmental concerns. Increasing levels of greenhouse gas emissions and depletion of fossil fuels are the main driving forces behind efforts to effectively utilise various sources of renewable energy. Renewable energy sources such as solar, wind, hydropower and biogas show strong potential to meet global energy requirements in a sustainable way. Solar thermal energy is the most abundant source, and is available in both direct as well as indirect forms. The Sun emits energy at a rate of 3.8×10^{23} kW, of which, approximately 1.8×10^{14} kW is intercepted by the earth. About 60% of this amount, or 1.08×10^{14} kW, is absorbed by the surface of the earth. The remainder is reflected into space and absorbed by the atmosphere. In just 1 h, energy absorbed by the earth is more than the energy consumed in the whole world for 1 year. The annual solar energy that reaches the earth's surface is approximately 3400,000 EJ. This is an order of magnitude greater than all the estimated (both discovered and undiscovered) non-renewable energy resources, including fossil fuels and nuclear [1].

Fig. 1 shows the average annual growth rates of various renewable energy sectors over the period 2007 to 2012. During this five year period, the installed capacity of many renewable energy technologies grew very rapidly, with the fastest growth occurring in the power sector. Demand has also increased rapidly in the heating/cooling sector, particularly for solar thermal systems, geothermal ground-source heat pumps, and bioenergy fuels and systems. The capacity of glazed solar water heaters has increased by an average exceeding 15% over the last five years. By 2012, the global solar thermal capacity reached an estimated 282 GW_{th} for all collector types, with the capacity of glazed water collectors reaching an estimated 255 GW_{th}. The majority of installed solar heat capacity is in China and Europe, which accounts for more than 90% of the world market and 81% of total capacity in 2011 [2].

The development of solar domestic hot water (SDHW) systems began in the 1760 s in Geneva, Switzerland, when Horace-Bénédict de Saussure, a Swiss naturalist, observed that water fluid and surroundings become hotter when the sun's rays passed through a glass-covered structure. He put this hypothesis under scientific scrutiny in 1767 when he built an insulated box with its bottom painted black to absorb as much solar energy as possible.

In 1891, Clarence Kemp, an American plumbing and heating manufacturer, placed a black-painted storage vessel inside a glass-covered box of similar design to de Saussure's. This was the first commercial solar water heater called "The Climax" which produced hot water (38.8 °C) on sunny days. As California has a good supply of solar energy, by the late 19th century, about a third of the homes in Pasadena California had water heated from the sun. Kemp's concept was further implemented as an integral collector storage solar water heater [3].

From the early 1900s, several researchers focused their attention on improving the design of SDHW systems to make them more durable and efficient. In 1909, William J. Bailey found a way of separating solar heating of water from its storage vessel. His solar collector consisted of water pipes housed inside a glass-covered box which was connected to an insulated remote storage tank located above the collector. As the solar energy heated the water, it became lighter, allowing cool water to enter from the bottom and hot water to rise into the storage tank. Bailey called his company the "Day and Night Solar Water Heater Company" and his products soon drove "The Climax" out of business and became the dominant solar water heater business in California, Arizona and Hawaii. Bailey's system was the first to use an insulated storage tank that relied upon the thermosyphon principle to circulate water between the solar collector and storage tank [3].

Since 1980, the use of SDHW systems has increased at a rate of about 30% annually [4]. The technology is now well-established. The achievement of this status is the outcome of a century of development. Solar water heaters are gaining popularity since they are relatively inexpensive, simple to fabricate and easy to maintain [1]. Although

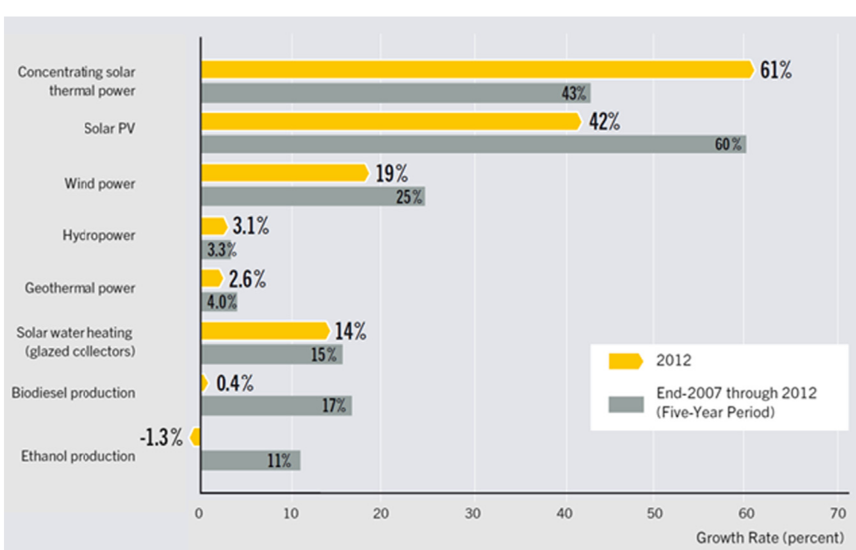

Fig. 1. Average annual growth rates of renewable energy capacity, for end 2007 to 2012 [2].