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Thermal energy storage system integration forms for a sustainable future

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ABSTRACT

There is an increasing awareness that there are limits to the availability of non-renewable resources, while there is an increasing energy demand throughout the world. This demand is expected to be satisfied through the efficient renewable energy in the near future. However, the world is facing the challenge of variable renewable energy outputs due to a stochastic feature of the energy sources. Thermal energy storage (TES) can be a good option for mitigating the effects of intermittent renewable resources on the networks. It can not only allow the increased renewable energy and night time low price electricity utilization, but also provide flexibility and ancillary services for managing future electricity supply/demand challenges. In this paper, various TES forms, including sensible, latent and sorption are explained and summarized for their performance enhancement. More importantly, from the perspective of sustainability, various integration forms for different applications are systematically introduced, such as TES integration with hot water supply, air conditioners and heat pumps, TES integration with building construction systems, and TES integration with power production cycles, cogeneration, food transport, solar cookers and vehicle systems for thermal comfort. Therefore, this study is beneficial to designing more sustainable thermal systems by the researchers and engineers.

Contents

Abbreviations: AB, auxiliary boiler; ASHP, air source heat pump; ATES, aquifer thermal energy storage; CHP, combined heating and power; CSP, concentrating solar power; COP, coefficient of performance; DHC, district heating and cooling; ESD, greenhouse gas; GHG, greenhouse gas; LHTES, latent heat thermal energy storage; SPF, seasonal performance factor; TES, thermal energy storage; PCM, phase change material; PM, prime moverprime moverprime mover

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1. Introduction

Fossil fuels play a significant role in the modern society. Used primarily for the heat and power production for the residential and commercial applications or as liquid fuels for the transportation sector, fossil fuels can eventually cause the large greenhouse gas (GHG) emissions. Such emissions are known to consequently contribute to the climate change and global warming, while at the same time they can lead to seriously deteriorated living environment and disease, etc. Moreover, there are also other serious issues relating to the use of non-renewable fossil fuel feedstock, particularly the security of supply and their limited availability. Facing such challenges, many countries have been trying to consider about using renewable resources to reduce GHG emissions in the near future. Moreover, the European Commission has set a target of achieving 20% of the total energy budget from the renewable sources by the year 2020 [1], which will stabilize the CO_2 emission, thus reducing the contribution to global warming. The renewable energy share in the US energy mix was 7.5% in 2010 [2], including 2.5% renewable power, 1.6% liquid biofuels and the remaining 3.4% of largely solid biomass used for heating in the manufacturing industry and buildings. Through the utilization of the existing renewable energy technologies, it is technically feasible and cost-effective to increase the renewable energy share in the total final energy consumption to 27%. This would save between $30 and $140 billion per year for the US economy by 2030 considering the benefits resulting from the reduced health effects and CO_2 emissions [2]. The industrial manufactures are also responsible for and making careful plans to relieve the global warming issues. As a global diversified industrial company, Ingersoll Rand provides products, services and solutions for heating/cooling loads for buildings, transportation, etc. It sticks to the climate commitment that it will cut the refrigerant-related GHG footprint of its products by 50% by 2020 and incorporate lower global warming potential (GWP) alternatives across its portfolio by 2030. In addition, it will invest $500 million in product-related research and development over the next five years so as to fund the long-term reduction of GHG emissions. Moreover, it will reduce the company operations-related GHG emissions by 35% by 2020 [3]. The renewable or low-grade waste energy resources can be the solar energy, wind energy, biomass, and industry low temperature waste energy, etc. The utilization of the thermal energy storage (TES), which has greatly attracted the scientific and industry community, can be a good option for the energy management to relieve the energy challenge nowadays. Through the efficient utilization of the renewable or low-grade waste energy resources, or the night time low-price electricity for the energy storage, TES can narrow the gap between the global energy demand and the supply in various applications. In general, the thermal energy can be stored in the sensible, latent and sorption forms [4,5]. The sensible form is to utilize the specific heat of the storage media, mostly the air and water, to store and release energy [6]. As for the latent form, it is to store and discharge the latent heat of phase change materials (PCMs) at the narrow phase transition temperature interval, for which a more compact storage unit can be achieved [7]. The sorption is a general phenomenon resulting from the interaction between an absorbent/adsorbent and a refrigerant. The energy is absorbed or released based on the reversible reaction between the two substances, as can be found later in Section 2.3. Various storage forms have specific advantages, as shown in Table 1 and Fig. 1.

To the best knowledge of the author, there is a lack of the comprehensive summary work for various TES integration forms. Therefore, in this study, various TES forms, including the sensible, latent and sorption are explained and summarized for their performance enhancements. More importantly, from a perspective of sustainability, an attempt is conducted to introduce various integration forms for various applications. Each application is detailed and perspectives are shown in the paper, which are beneficial to designing more sustainable thermal systems by researchers and engineers.

2. Performance enhancements of thermal energy storage techniques

In this section, various TES form performance enhancements are introduced and summarized.

2.1. Water stratification enhancements for sensible TES

Thermal stratification phenomenon in the sensible TES plays an important role in the performance evaluation. Based on the case of domestic hot water, during the charging process, the thermal

Table 1
Various TES form comparison.

	Sensible	Latent	Sorption
Storage medium	Water, gravel, pebble, soil.	Organics, inorganics	Working pair
Advantage	Cheap, simple, easy for control	High energy density, compact, isothermal temperature	High energy density, compact,
Disadvantage	Large volume, low energy density, geological requirements	Crystallization, high material, corrosion	Poor sorption bed heat transfer
Current status	Large-scale demonstration plants	Laboratory-scale prototypes	laboratory-scale prototypes
Performance enhancement focused in this study	Water stratification	Latent tank heat transfer	Sorption bed heat transfer