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Cost Analysis of Two High Temperature Thermal Energy Storage Techniques for Large Scale Concentrating Solar Power (CSP) Applications

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Abstract

The existing and under construction concentrating solar power (CSP) incorporated the two-tank sensible storage system using molten salt as the storage medium. Compared to sensible heat storage, high temperature latent heat storage using phase change materials (PCMs) can provide a smaller storage system, potentially reducing the cost of thermal storage for CSP plants. This paper demonstrates an economic evaluation of two high temperature thermal energy storage techniques for large scale concentrating solar power (CSP) applications. The economic calculation code

using MATLAB has been developed to estimate the size and cost of high temperature triplex tube storage system and high temperature storage system using finned heat pipes, and compared with publically-available information for a two-tank sensible heat thermal energy storage (SHTES) system.

1. Introduction

Energy consumption has increased substantially over the last 30 years. It has led to an increase of greenhouse gas emissions and, as a result, climate change, as well as a rise in energy costs. Concentrated Solar Power (CSP) systems have an important role to fill in an optimum portfolio of future clean energy technologies (Fthenakis et al., 2009). Thermal energy storage reduces CSP-generated electric power net cost. Existing thermal energy storage systems for CSP applications have all been based on sensible heat thermal energy storage (SHTES). The disadvantages of SHTES are the large amount of medium (salt) required to store the thermal energy (and the two correspondingly large storage tanks). Latent heat thermal energy storage (LHTES) requires less storage volume. Several researchers have investigated the integration of heat pipes and triplex tube thermal energy storage system (TTTESS) with eight fins into a PCM and heat transfer fluid (HTF) heat exchanger. These approaches have been further improved numerically and validated experimentally by (Almsater et al., 2016) and (Almsater et al., 2017). However, In this study, an economic evaluation of these systems are carried out, and the designs are compared with a two-tank SHTES to determine whether LHTES with embedded finned heat pipes and TTTESS with eight fins can be cost-competitive.

Nomenclature

SHTES	Sensible heat thermal energy storage
LHTES	Latent heat thermal energy storage
TTTESS	Triplex tube thermal energy storage system
C_p^*	The PCM cost
C_f''	Foundation cost

2. The Cost Model of Triplex Tube Storage System

Using MATLAB, a cost analysis model for a high temperature TTTESS has been developed. The total cost of TTTESS can be expressed as the summation of storage material Cost (HTF and PCM), container cost, and overhead costs. The overhead costs, accounting for the miscellaneous costs such as electrical, instrumentation, piping, valves and fitting costs is assumed to be 10% of the storage material container cost (Nithyanandam and Pitchumani, 2014). The suggested size of TTTESS for 50 MWe output, is 25.4 *m* container width, 12.4 *m* container height, and 40.2 *m* container length is appropriate, containing approximately 23,000 metric tons of PCM. The PCM cost per unit mass C_p^* was obtained from (Xu et al., 2015).

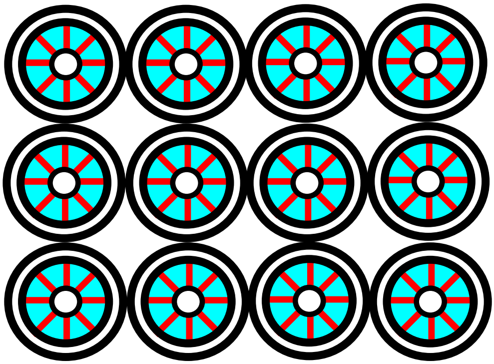

Figure 1. High temperature TTTESS.

The cost of the TTTESS container which is shown in Figure 1 is calculated as explained in (G. Glatzmaier, 2011), which encompasses the material cost of 321 stainless steel, foundation cost and the insulation cost, the calcium silicate insulation cost C_l'' is assumed to be \$235/m2 (Kelly and Kearney, 2006), and the foundation cost C_f'' is taken as \$1210/m^2 (Kelly and Kearney, 2006). The cost values reported here are consistent with the values of two-tank molten salt thermal storage system reported in (G. Glatzmaier, 2011).

3. The Cost Model of Finned Heat Pipe Storage System

Figure 2 shows the finned heat pipe storage system, which was described in (Almsater et al., 2016). The total cost of latent heat thermal energy storage (LHTES) using finned heat pipes can be expressed as the summation of storage material cost (HTF and PCM), container cost, finned heat pipes cost and overhead costs.

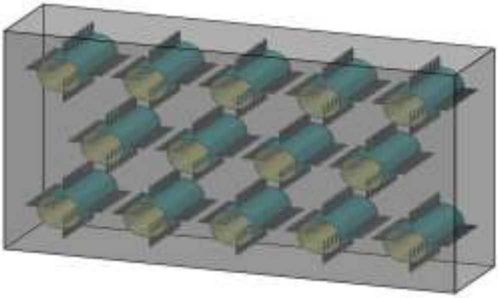

Figure 2. High temperature finned heat pipe system (Almsater et al., 2016).

The overhead costs are assumed to be 10% of the storage material, container and finned heat pipes cost as discussed above. The suggested size of finned heat pipe storage system for 50 MWe output, is 28.6 *m* container width, 13.6 *m* container height, and 44.9 *m* container length is appropriate, containing approximately 30,000 metric tons of PCM. The finned heat pipes cost is calculated as $N_{HP} * C_{HP}$.

4. Results and Discussion

The economic calculation code presented in Section 2 and 3 was created using MATLAB. The model for heat pipe storage system was validated with the results in

(Robak et al., 2011) from Figure 3 it is clearly seen that the model predictions agree well with the results in (Robak et al., 2011).

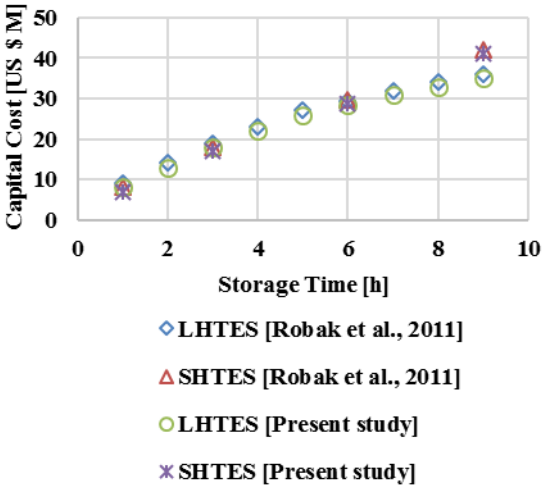

Figure 3. Comparison of capital costs for the LHTES and SHTES for different storage times. The power generation is 50 MWe.

4.1 The Triplex Tube Storage System and the Finned Heat Pipes System

The dimensions of the TTTESS, which give 50 MW and 9 hours storage capacity, are 25.4 *m* container width, 12.4 *m* container height, and 40.2 *m* container length. The overall model suggests that, for 50 MWe output and the dimensions suggested is appropriate, containing approximately 23,000 metric tons of PCM. For the finned heat pipe, the storage for 50 MWe output and 9 hours storage capacity is 28.6 *m* container width, 13.6 *m* container height, and 44.9 *m* container length. For comparison, 50 MWe SHTES system as reported in (Herrmann et al., 2004). The TTTESS reduces the required overall tank volume by approximately 83%, and reduces the thermal energy storage (TES) medium mass by approximately 45%. The finned heat pipe system reduces the required overall tank volume by approximately 87%, and reduces the thermal energy storage (TES) medium mass by 28%. Figure 4 demonstrates a comparison between the estimated capital costs of the TTTESS, the finned heat pipe system, and a SHTES reported in (Robak et al., 2011). For a 50 MWe unit with 9 h storage, using the minimum costs identified in (Robak et al., 2011). Overall, the TTTESS is estimated to have an approximate capital cost of $32 M, compared with $42 M for a SHTES system. Overall, the finned heat pipe system is estimated to have an approximate capital cost of $37 M, compared with $42 M for a SHTES system and $35 M for LHTES. In total, the economic calculation model suggests that at least 12% capital cost savings over SHTES can be relaized using finned heat pipe system. Most of the savings are associated with reduced expenditures for the energy storage medium and the storage container. In total, the economic calculation model suggests that at least 23% capital cost savings over SHTES can be realized using TTTESS.

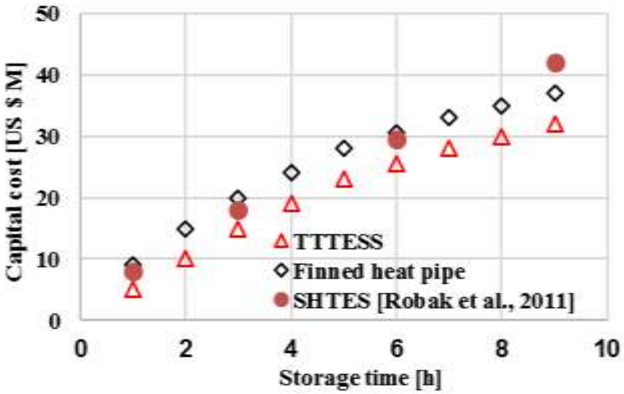

Figure 4. Capital costs for TTTESS and Finned heat pipe system compared with a SHTES for different storage times. The power generation is 50 MWe.

4.2 Sensitivity Analysis

In this section, a sensitivity analysis has been developed using the MATLAB model to investigate the effect of the price ranges for the major cost components, as the PCM unit cost is varied between $2.65/kg and $6.5/kg. When the comparison is made using the maximum costs, the TTTESS and finned heat pipe systems are always less expensive than the SHTES, and finned heat pipe system. The difference reaches 8% when the PCM is at the expensive price of $6.5/kg. The impact of the finned heat pipe unit cost is economically competitive in comparison to the SHTES cost up to approximately $4. The effect of 321 stainless steel cost on the TTTESS and finned heat pipe system capital cost indicates that, as the price of 321 stainless steel increases from \$2.20/kg to \$7.04/kg, the TTTESS and finned heat pipe system capital costs slowly increase and approach the SHTES capital cost scenarios.

5. Conclusion

A large scale TTTESS with a volume of 12661.392 m^3 can be cost competitive with two-tank SHTES systems with volume of 46232 m^3 and with a finned heat pipe system with volume of 17464.304 m^3 for the output conditions of 50MW and nine hours storage capacity. Potentially, a 24% reduction in capital cost might be realized for the proposed latent heat thermal energy storage over the corresponding SHTES.

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Acknowledgements

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