China Petroleum Processing and Petrochemical Technology

Catalyst Research Volume 23, Issue 2, July 2023 Pp. 2780-2786

DEVELOPMENT OF THERMAL ENERGY STORAGE MEASURE BY USING THERMODYNAMIC ANALYSIS

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Abstract:
Understanding the distinct roles of compressed air energy storage, batteries, and thermal energy storage (TES) is essential for effectively meeting heating and cooling demands in an energy-efficient and cost-effective manner. This study is dedicated to evaluating and comparing these storage technologies, with a specific focus on Thermal Energy Storage (TES), to quantify its impact on a building's heating and cooling requirements. The primary objective of this research is to analyze the influence of TES measures on heating and cooling demands within a building, with a keen emphasis on system efficiency and boiler cycling. Through a comprehensive thermodynamic analysis and modeling of TES systems, varying in storage capacities, this study seeks to demonstrate the considerable potential of TES in optimizing peak thermal loads. This optimization, in turn, can lead to a reduction in the required boiler or chiller capacity, ultimately enhancing the overall efficiency of the thermal system.
Keywords*:* Thermodynamic Analysis, Thermal Energy, heat transfer fluid, DSM, MECS.

INTRODUCTION

The pervasive use of heating, cooling, and HVAC systems across diverse sectors highlights the significance of advancing energy efficiency in this domain. Thermal Energy Storage (TES) has

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emerged as a promising technology in this context, aiming to enhance energy efficiency. For instance, in 2012, approximately 20% of the energy consumption in commercial buildings, equating to around 1,650 million MMBtus [1].

The demand for heating, cooling, or power is rarely consistent and can fluctuate over time. During periods of lower demand, excess generation capacity can be employed to charge Thermal Energy Storage, effectively increasing the generation capacity. This approach enables a smaller production component to be utilized or capacity to be added without acquiring additional units, resulting in a higher load factor for the component.

A noteworthy advantage of a Thermal Energy Storage system lies in its capacity to reduce electric costs by utilizing off-peak electricity to generate and store energy for daytime cooling. Thermal Energy Storage systems have proven successful in various settings, including offices, schools, hospitals, airports, and universities across many countries, effectively electricity rate period to off-peak ones. While energy efficiency is a commonly used metric to evaluate Thermal Energy Storage performance, it is inadequate in assessing the system comprehensively, as it overlooks factors such as performance proximity to ideality, storage duration, and environmental temperatures during thermal energy input and retrieval.

Energy analysis emerges as a comprehensive and insightful alternative storage system. Energy analysis provides efficiencies that offer a true reflection of how closely the actual performance aligns with the ideal scenario. Additionally, it allows for a clearer understanding of the magnitudes, causes, and locations of thermodynamic losses compared to traditional energy analysis. Consequently, energy analysis proves instrumental in refining and optimizing Thermal Energy Storage system designs.

Potential Benefits of TES

The energy consumption for end users can significantly fluctuate throughout the day or year due to variations in fuel supply and demand. Thermal Energy Storage offers an accessible means to implement Demand Side Management (DSM) in a system. DSM plays a crucial role in reducing energy costs within a thermal system by managing peak demands and aligning loads with energy price fluctuations [5]. This serves as an incentive for users to shift their energy usage away from peak periods. By doing so, utilities can delay the necessity for additional generation capacity, thereby optimizing the utilization of base load plants.

METHODOLOGY

The constructed models have been streamlined to their fundamental elements, aiming to generate a comprehensive evaluation of Thermal Energy Storage sizing that can be swiftly applied across a diverse range of thermal systems. With the models' uncomplicated controls and a minimal set of user-required input parameters, the model can be promptly adjusted to offer a qualitative assessment of the integration of Thermal Energy Storage. This involves modifying boiler capacity in line with the envisioned system.

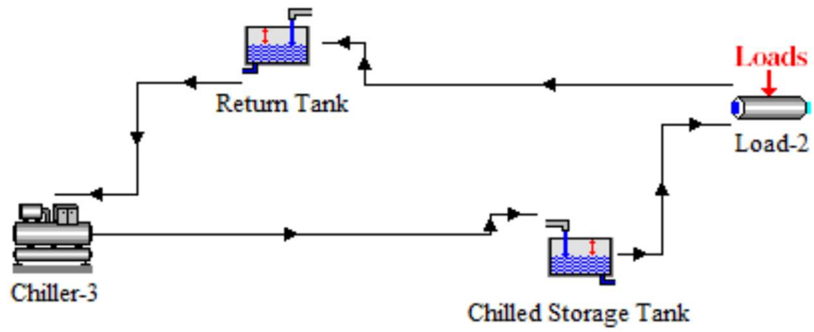

Figure 1: The preliminary heating and cooling models

The simulation utilized heating and cooling load data, representing the thermal output of the boiler or chiller. Initial models for each system were introduced to give insight into the ultimate design of the heating and cooling model. In both preliminary models, a stratified storage tank was employed, but after careful consideration, it was determined that a separate return and supply tank would be more effective..

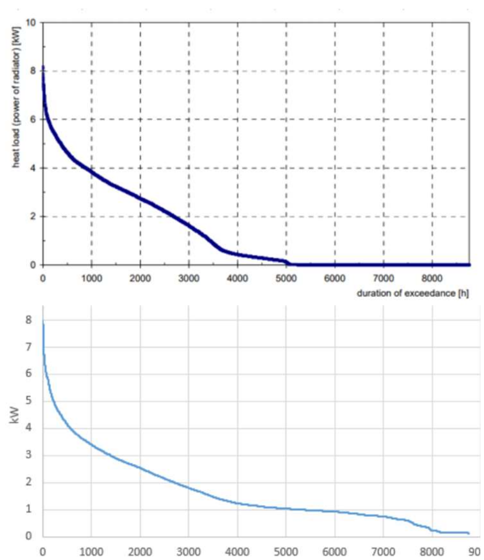

Figure 2: Graph of heat load

EXPERIMENTAL RESULTS

This performance metric expression provides a succinct approach to compare Thermal Energy Storage (TES) with electrical storage technologies, particularly focusing on electrical energy. The central concept of round trip efficiency and/or turn around efficiency is condensed into a term referred to as "storage efficiency" within this framework. The thermodynamic model encompasses fundamental equations governing the heat transfer processes involving the heat transfer fluid

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(HTF) and molten salt storage. It also accounts for losses occurring in the heat exchanger and losses within the molten salt storage tank.

In simulating the heating model, the original hourly unscaled heating load associated with the retirement community's energy model was used. The load data indicated peaks at approximately 0.69 MM Btu/h. Throughout the simulation, the boiler's operational capacity was allowed to modulate, ranging from 100% to 35% of its rated capacity. This capacity range is determined to adequately cover the annual peak heating load.

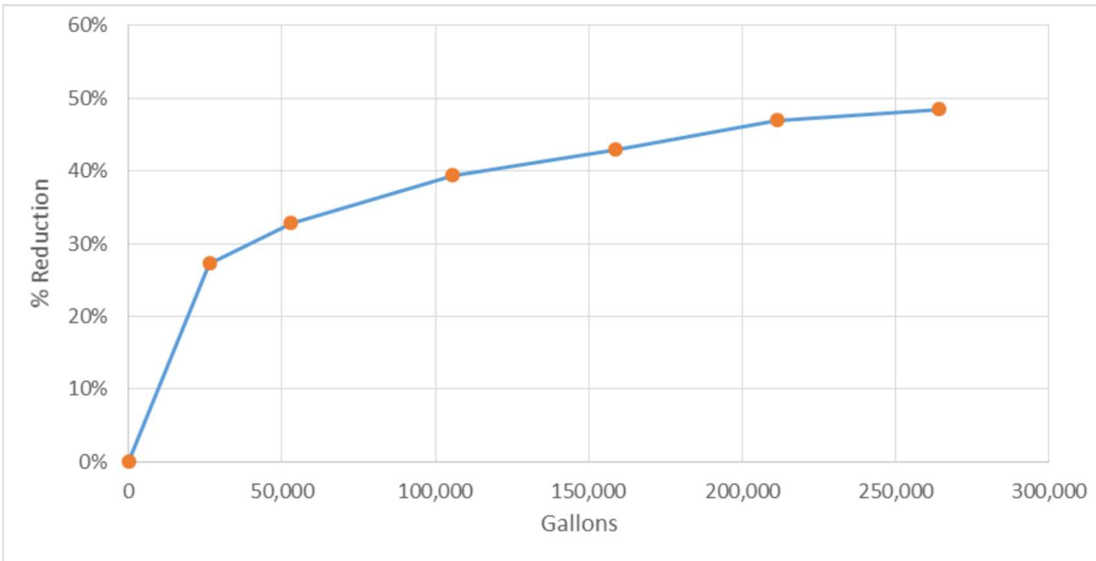

Figure 3: Reduction Ratio during heat fluid

The incorporation of 263,126 gallons (1,000 m3) into the total storage volume resulted in a significant 45% decrease in the necessary boiler capacity, lowering it from 698 kBtu to 356 kBtu/hr. This reduction corresponds to about 0.123 kBtu per hundred gallons of additional storage. Notably, the most substantial reduction in boiler capacity was observed with the initial 26,425 gallons (100 m3) of added storage, culminating in an impressive 27% decrease in boiler capacity, equating to a capacity reduction of 0.698 kBtu per hundred gallons. However, as the storage volume was further increased, the subsequent gains in reducing the required boiler capacity diminished. For instance, an increase from 211,336 gallons (800 m3) to 264,162 gallons (1,000 m3) resulted in a mere 1.4% decrease in the necessary boiler capacity.

CONCLUSION

The primary objective of this study was to analyze the impact of varying Thermal Energy Storage (TES) capacities on the design and operation of heating and cooling systems. To achieve this, distinct models for heating and cooling water storage systems were developed using the TRNSYS simulation software. These models were designed to be flexible and adaptable to any hourly load input, providing an initial evaluation of Thermal Energy Storage feasibility.

The simulations encompassed diverse storage capacities to investigate the relationship between storage size, boiler cycling, and chiller load shaping. In the heating model, augmenting the total storage by 13,203 gallons (50 m3) led to a substantial 56% reduction in boiler cycling. However, as storage volume increased, the reduction in boiler cycles per hundred gallons of storage volume became progressively less pronounced.

On the cooling side, the model demonstrated that peak energy usage could be notably decreased, declining from 40% to 22%, with the inclusion of 52,864 gallons (200 m3) of storage. Furthermore, a remarkable 99% of on-peak loads could be shifted to the off-peak period with 211,398 gallons (800 m3) of storage.

A thorough exploration of varying Thermal Energy Storage volumes involved leveraging TES to enhance the effective capacity of heating and cooling systems. The models were deliberately simulated with reduced boiler and chiller capacities compared to conventional requirements for meeting annual peak loads. This was aimed at evaluating how TES could potentially enable boilers and chillers to cater to demands surpassing their peak capacities. The findings revealed that 26,419 gallons (100 m3) of storage volume facilitated a 7.5% reduction in minimum chiller capacity and an impressive 27.6% reduction in minimum boiler capacity, assuming that the minimum capacity for each aligned with their respective peak thermal load in the absence of storage.

FUTURE WORK

In this research, we intentionally treat Thermal Energy Storage (TES) capacity as an aggregate measure of thermal energy without imposing specific restrictions on its storage or utilization. However, to augment the usefulness of the models developed in this study, a more comprehensive examination of the integration and control mechanisms pertaining to TES is imperative. This would enable a more accurate representation of system efficiency resulting from TES at varying capacities. Key aspects that merit in-depth consideration include the maximum heat transfer rate of TES, additional pump energy consumption attributable to TES, standby losses, system demand reduction facilitated by TES, potential integration of multiple boilers or chillers, and the impact of TES on the operating efficiencies of boilers and chillers.

This scrutiny becomes particularly pivotal when evaluating how TES can augment boiler and chiller capacity. By incorporating these nuanced features related to varied TES volumes into the simulation control framework, it becomes feasible to estimate annual energy consumption, cost implications, and emissions. Leveraging the proposed models in conjunction with contemporary insights into TES technology and csost data can offer an invaluable tool for prospective adopters of this technology.

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