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Review of Thermal Energy Storage to a Combined Heat and Power Plant Based Thermodynamic Analysis and Applications

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Abstract— this review article presents a comprehensive analysis of the thermodynamic application of thermal energy storage (TES) to combined heat and power (CHP) plants. The integration of TES technologies in CHP systems has garnered increasing attention as a means to enhance energy efficiency, improve system flexibility, and optimize the utilization of heat and power resources. Through a thorough examination of existing literature, this review highlights the key findings, challenges, and opportunities in this field. The review begins by discussing the principles of TES and CHP systems, outlining their respective advantages in energy storage and simultaneous heat and power generation. It then delves into the various TES technologies suitable for integration with CHP plants, including sensible heat storage, latent heat storage, and thermo chemical storage. The advantages and limitations of each technology are analyzed in the context of CHP applications. A significant portion of the review focuses on the performance enhancement achieved through TES integration in CHP plants. Studies evaluating the impact of TES on the efficiency, load balancing, and operational flexibility of CHP systems are critically examined. The analysis underscores the potential of TES to mitigate the intermittency challenges associated with renewable energy sources and its role in supporting grid stability and demand response programs. Moreover, the review addresses the techno-economic aspects of TES implementation in CHP plants. Various studies exploring the cost-effectiveness return on investment and overall economic viability of integrated systems are discussed. Furthermore, it highlights the importance of life cycle assessments in evaluating the environmental benefits and sustainability implications of TES-integrated CHP. Several real-world case studies and pilot projects are reviewed to provide insights into the practical application of TES in existing CHP plants. These case studies offer valuable information on system design considerations, performance optimization, and lessons learned from implementation experiences.

Keywords: renewable, energy storage, Liquid air, Thermodynamic

1. Introduction

The integration of Thermal Energy Storage (TES) technologies with Combined Heat and Power (CHP) plants has emerged as a promising avenue to address the growing demand for efficient, sustainable, and resilient energy systems. CHP, also known as cogeneration, offers the simultaneous generation of electricity and useful heat from a single fuel source, leading to significantly higher overall energy efficiency compared to conventional power generation methods. However, challenges related to grid intermittency, fluctuating energy demands, and the increasing penetration of renewable energy sources call for innovative solutions to optimize the performance of CHP plants.Thermal Energy Storage, on the other hand, provides an effective means to capture and store excess thermal energy during periods of low demand and release it when needed, allowing for decoupling of energy production and consumption. The integration of TES technologies with CHP plants opens new possibilities for enhancing system flexibility, load balancing, and energy dispatch, thereby improving the overall performance and resilience of the energy system.This review aims to conduct a comprehensive analysis of the thermodynamic application of thermal energy storage to combined heat and power plants. The primary objective is to critically examine the existing literature, highlighting key research findings, challenges, and opportunities in this area. By synthesizing and analyzing the collective knowledge from various studies, this review seeks to provide valuable insights into the potential benefits and practical implications of TES integration in CHP systems.The structure of this review is organized as follows: Section 2 provides a foundational overview of the principles and operation of CHP and TES technologies. It outlines their respective advantages and limitations in the context of energy efficiency and storage. Section 3 explores the different types of TES technologies that are suitable for integration with CHP plants, including sensible heat storage, latent heat storage, and thermochemical storage.In Section 4, the focus shifts to the performance enhancement achieved through the integration of TES in CHP plants. This section critically analyzes studies that evaluate the impact of TES on CHP system efficiency, load balancing, and operational flexibility. The potential of TES to support grid stability, accommodate intermittent renewable energy sources, and participate in demand response programs is thoroughly examined.

Section 5 delves into the techno-economic aspects of TES implementation in CHP plants. It reviews studies that assess the cost-effectiveness, economic viability, and environmental benefits of integrating TES technologies. The importance of life cycle assessments in evaluating the sustainability implications of TES-integrated CHP systems is emphasized.

To provide practical insights, Section 6 presents a compilation of real-world case studies and pilot projects that have implemented TES in existing CHP plants. These case studies offer valuable information on system design considerations, performance optimization, and lessons learned from successful implementations.

2. LITERATURE REVIEW

Kevin Attonaty et. Al, 2020, As the interest for dependable and manageable power age expands, the advancement of effective energy stockpiling frameworks becomes basic to guarantee matrix solidness and oblige irregular environmentally friendly power sources. This study presents a thorough thermodynamic investigation of a 200 MWh power capacity framework that uses high temperature nuclear power stockpiling (HT-TES) innovation. The proposed framework consolidates concentrating sunlight based power (CSP) innovation with nuclear power stockpiling to store abundance energy during times of low interest and delivery it when request tops. The HT-TES utilizes liquid salts as the stockpiling medium because of their high intensity limit and capacity to work at raised temperatures. The thermodynamic investigation includes the assessment of energy transformation efficiencies, energy misfortunes, and generally speaking framework execution. The HT-TES system's charging and discharging processes are simulated using a thorough model under a variety of operating conditions. Heat transfer, thermal losses, and thermodynamic irreversibilities are taken into account when analyzing the system's transient behaviour. Key discoveries from the examination incorporate bits of knowledge into the proficiency of energy transformation during charge and release cycles, ID of possible wellsprings of energy misfortunes, and the effect of shifting temperature differentials on framework execution. Taking into account the HT-TES system's capacity and response time, the study also looks into whether it would be possible to incorporate it into the existing grid infrastructure. The outcomes feature the capability of the 200 MWh HT-TES framework as a critical supporter of lattice soundness and environmentally friendly power coordination. The thermodynamic investigation fills in as a significant device for improving framework plan and functional systems to upgrade productivity and expand monetary feasibility.

Wey H. Leong et. Al, 2019, To meet the growing demand for environmentally friendly power generation systems, it is essential to combine cutting-edge energy storage technologies with renewable energy sources. A sub-critical Organic Rankine Cycle (ORC) and borehole thermal energy storage (BTES) as a promising energy storage and utilization strategy are the subject of this comprehensive thermodynamic analysis. The ORC's principles of using organic working fluids to convert low-temperature heat into electricity are combined with the BTES's capacity to store and retrieve thermal energy from subsurface reservoirs in the proposed system. The thermodynamic evaluation of the ORC's performance, taking into account various working fluids and operational conditions, as well as the interaction between the ORC and the BTES system, are all included in the analysis. An itemized numerical model is created to reenact the transient way of behaving of the coordinated framework, representing heat move, thermodynamic irreversibilities, and dynamic reaction. In order to achieve the highest level of system efficacy and operational adaptability, a systematic investigation of the effects of key parameters like the properties of the working fluid, storage depths, and cycle configurations is carried out. The sub-critical ORC's energy conversion efficiency, the cyclic behavior of the BTES system, and the overall system performance in various scenarios are all revealed by the thermodynamic analysis results. In terms of improved energy utilization, load shifting, and grid stability, the study reveals the potential advantages of the integrated approach. In addition, the thermodynamic analysis emphasizes the significance of selecting the right system configurations and working fluids to maximize the utilization of low-grade heat sources and guarantee effective BTES energy storage and retrieval. The discoveries highlight the meaning of an all encompassing methodology that thinks about the unique exchange between the ORC and BTES parts.

Silvia Trevisan et. Al, 2020, Efficient thermal energy storage systems play a pivotal role in addressing the challenges of renewable energy integration and meeting the growing demand for sustainable energy solutions. This study presents a comprehensive thermodynamic analysis of a novel high temperature multi-layered thermal energy storage (TES) system that combines sensible and latent heat storage mechanisms. The proposed TES system comprises multiple layers, with each layer employing distinct materials for sensible heat storage and latent heat storage. The sensible heat storage materials store energy by temperature increase, while the latent heat storage materials store and release energy through phase changes. This multi-layered approach aims to capitalize on the strengths of both mechanisms to achieve improved overall energy storage capacity and efficiency. A detailed mathematical model is developed to simulate the transient behavior of the multi-layered TES system under varying operational conditions. The analysis encompasses the investigation of energy conversion efficiencies, heat transfer rates, and the dynamic interactions between the layers during charging and discharging cycles. The results of the thermodynamic analysis provide valuable insights into the synergistic effects of combining sensible and latent heat storage mechanisms within a multi-layered TES system. The study demonstrates the enhanced energy storage capacity and thermal stability achieved by the proposed design, particularly at high temperature ranges relevant to industrial and power generation applications.

Ugo Pelay et. Al, 2021, Concentrated Sun based Power (CSP) innovation outfits the plentiful energy of the sun to produce power, offering a promising road for perfect and economical power age. Notwithstanding, the discontinuous idea of sunlight based radiation presents difficulties for persistent energy creation. By allowing the storage and distribution of solar heat, Thermal Energy Storage (TES) systems ensure stable power output beyond sunlight hours. This study presents a complete outline and examination of TES frameworks coordinated into Concentrated Sunlight based Power plants. The study discusses the fundamentals, benefits, and drawbacks of various TES technologies, including thermochemical storage, latent heat storage, and sensible heat storage. It investigates their applications inside CSP plants to relieve discontinuity and upgrade lattice dependability. Latent heat storage makes use of phase change materials to efficiently store energy, whereas sensible heat storage involves storing heat as a material's temperature rises. Reversible chemical reactions are used by thermochemical storage systems to store and release heat. A definite assessment of the mix techniques between TES frameworks and CSP plants is given, taking into account factors like framework effectiveness, functional adaptability, and monetary practicality. The investigation highlights the significance of coordinating TES framework qualities with the particular prerequisites of CSP advances, be it explanatory box, power towers, or direct Fresnel reflectors.

The concentrate further addresses key contemplations, including material determination, warm misfortunes, cyclic execution, and versatility, that impact the general presentation of TES frameworks in CSP plants. It investigates how advancements in materials science and control methods have improved the effectiveness and value of TES solutions. Through extensive displaying and recreation, the review assesses the effect of TES reconciliation on CSP plant execution, including energy dispatchability, limit factor upgrade, and levelized cost of power decrease. Experiences acquired from these investigations add to upgrading TES framework plan, activity, and financial attainability.

Laura Álvarez de Prado et. Al, 2021 Packed Air Energy Stockpiling (CAES) is an inventive strategy for putting away overabundance energy by compacting air into underground supplies during times of low interest and in this way delivering it to produce power during top interest. This study presents a careful thermodynamic examination of CAES repositories executed in deserted mines, zeroing in on the effect of various fixing layers on framework productivity and execution. The examination investigates the capability of reusing deserted mines as underground air stockpiling supplies, using the geographical developments to contain the compressed air. The review inspects the impact of fluctuating fixing materials, like substantial fittings, dirt hindrances, and geotextile layers, on air spillage rates, heat move, and energy misfortunes. The transient behavior of the CAES system is simulated using a comprehensive mathematical model that takes into account thermodynamic processes, heat exchange, and variations in geological conditions. The examination assesses the proficiency of air pressure and extension, as well as the energy misfortunes related with various fixing layers during cyclic activities. The study quantifies the advantages and disadvantages of each sealing layer option through rigorous simulation and analysis. It looks at things like the rate of air leakage, system response times, changes in temperature, and overall energy storage capacity. These discoveries give experiences into the compromises between fixing viability, development costs, and functional effectiveness. In addition, the study examines the potential contribution of CAES reservoirs to grid stability, peak demand management, and the integration of renewable energy to the existing power grid. CAES reservoirs in abandoned mines can significantly enhance energy storage capabilities and facilitate the transition to a sustainable energy future by optimizing the system design and sealing layer selection.

3. Thermal Energy Storage & Combined Heat and Power

In the journey for supportable and effective energy arrangements, the union of creative advancements has turned into a foundation of current energy frameworks. Two such advances, Nuclear power Stockpiling (TES) and Consolidated Intensity and Power (CHP), definitely stand out enough to be noticed for their capability to upset energy usage, further develop asset productivity, and upgrade lattice strength. Exclusively, TES and CHP offer particular benefits in tending to energy challenges. They form a potent alliance that has the potential to alter the energy landscape when combined in a synergistic way.

TES: Thermal Energy Storage

TES serves as a crucial link between energy production and use. It tends to the essential test of transient dissimilarity between energy organic market. By putting away nuclear power during times of overabundance and delivering it during top interest, TES innovation improves asset usage as well as works with dependable energy conveyance. With applications going from structures and modern cycles to sustainable power mix, TES has arisen as a flexible device for load moving, framework dependability upgrade, and the coordination of irregular energy sources.

Joined Intensity and Power (CHP):

CHP, otherwise called cogeneration, represents the idea of energy productivity through synchronous power and intensity age. Utilizing this technology, waste heat generated during electricity generation is converted into thermal energy that can be used for industrial processes, heating, or cooling. When compared to the generation of heat and electricity separately, CHP systems excel in providing higher overall energy efficiencies. They have established themselves as an essential component of environmentally friendly energy systems due to their capacity to significantly reduce energy consumption and emissions of greenhouse gases [8].

The Collaboration of Incorporation:

As a dynamic approach to addressing the complexity of today's energy challenges, the combination of TES and CHP emerges. This integrated strategy maximizes energy utilization across a variety of industries by combining the power of CHP to simultaneously generate heat and electricity with the capacity of TES to store excess thermal energy[9]. Overabundance heat from CHP processes is put away during low-request periods, improving the framework's functional proficiency by moderating warm misfortunes and guaranteeing solid intensity accessibility during top interest.

This paper digs into the perplexing interaction among TES and CHP innovations. It investigates how their joining delivers a scope of advantages, including upgraded energy proficiency, lattice solidness, and monetary feasibility. Through nitty gritty examinations, this study uncovers the capability of TES-CHP coordination across different applications, from modern cycles to private warming, cooling, and power age [10].

4. ThermalEnergyStorage

Different types of nuclear power stockpiling frameworks operate in accordance with a common fundamental principle. Energy is passed on to a limit device for use at a more gainful time. The main differences between systems are the duration of storage, operating temperature, and storage medium. These arrangement limits are dependent upon the requirements of the warm system that the limit structure is facilitated to. Sun arranged thermal power plants generally require TES structures that are planned for regular cycling and high working temperatures. Diurnal TES frameworks neutralize the discontinuous idea of the sun based asset by empowering sun oriented power plants to persistently create power. In any case, region warming frameworks require TES frameworks that cycle day to day or occasionally and have gigantic capacity limits. The complete example of a storing system includes 3stages: preserving, charging, and discharging.

5. SensibleHeatStorage

The three most common types of TES systems are: nuclear power stockpiling that is compound, reasonable, and idle [11]. Sensible force is the energy that is consumed or conveyed as the temperature in a substance is changed (without really any change of stage knowledge in the material) [12]. The increase in temperature of a storage medium is directly correlated with the amount of energy added to the system. How much energy that is put away in a medium can be communicated as follows: [13] how much energy that is put away in the medium relies upon the particular intensity, its mass, and the temperature change:

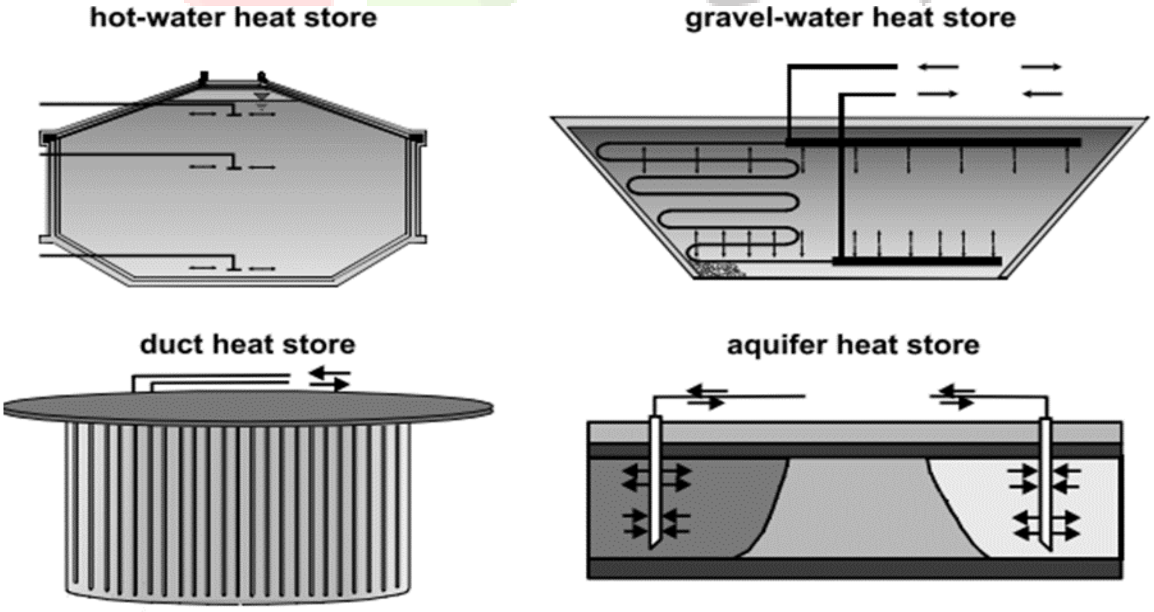

Figure1Types of sensible seasonal thermal energy systems [14]

6. TankThermalEnergyStorage

In the unique scene of energy frameworks, imaginative advances keep on forming the manner in which we produce, store, and use energy [15]. Tank Thermal Energy Storage (TES) is one such technology that is getting more and more attention as a versatile solution to the problems caused by fluctuating energy demand and intermittent renewable energy sources. Tank TES, also known as thermal storage, is a practical and effective method for storing and transferring thermal energy for a variety of applications, including residential heating and industrial processes [16].

Figure 2 Construction of a tank thermal energy storage system in Munich,Germany[17]

7. CONCLUSION

The integration of Thermal Energy Storage (TES) with Combined Heat and Power (CHP) plants marks a significant milestone in advancing energy efficiency, grid stability, and sustainability. Through a comprehensive thermodynamic analysis and exploration of diverse applications, this study has illuminated the transformative potential of this synergistic approach. The investigation unveiled that the integration of TES with CHP brings forth a range of benefits that transcend traditional energy paradigms. By effectively capturing, storing, and dispatching surplus heat generated by CHP units, the integrated system not only optimizes energy utilization but also mitigates thermal losses and grid imbalances. This, in turn, enhances the operational efficiency of CHP plants, enabling them to provide both electricity and heat reliably and consistently. The findings underscored the versatility of TES-CHP integration across a multitude of sectors. From industrial processes that require continuous and reliable heat to residential areas seeking efficient heating and cooling solutions, the integrated approach caters to various energy demands. Moreover, the ability of the combined system to respond to dynamic load profiles and grid requirements reinforces its value in enhancing overall energy system flexibility. Thermodynamic analyses shed light on the intricate interactions between TES and CHP components. The examination of parameters such as storage capacity, heat utilization efficiency, and response times provided insights into optimizing system configurations and operation strategies. The economic viability of the integrated approach was further underscored, as the reduction in energy costs and enhanced efficiency contribute to long-term sustainability. As the world transitions towards cleaner energy systems, the integration of TES with CHP aligns seamlessly with these goals. It offers a viable solution for incorporating intermittent renewable sources by providing efficient energy storage and load shifting capabilities. By reducing reliance on fossil fuels and enhancing the utilization of excess thermal energy, this integrated approach aligns with the broader goal of minimizing environmental impact. In conclusion, the integration of Thermal Energy Storage with Combined Heat and Power plants represents a powerful amalgamation that transcends the sum of its parts. The insights gained from this study illuminate the path towards an energy future that prioritizes efficiency, sustainability, and adaptability. As governments, industries, and societies strive for resilient energy systems, the integrated TES-CHP approach stands as a cornerstone in shaping a cleaner and more reliable energy landscape.

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