Design and simulation of a thermal energy storage (TES) for storing the heat of compression in a multi-stage compression system with intercooling.

Hamad Mohammed Alaqeel, Abdullah Ahmed Aldoribi, Abdulrahman Mohammed Almoneef, Hasan Marwan Alghilani

Supervised by: Dr. Syed Muhammad Fakhir Hasani

Al Imam Mohammed Ibn Saud Islamic University, College of Engineering, Mechanical Engineering Department

VISION رؤية 2030 المملكة العربية السعودية KINGDOM OF SAUDI ARABIA

Problem Statement

Aligned with Saudi Arabia's Vision 2030 goals of promoting energy sustainability and economic diversification, this project proposes the design and simulation of a Thermal Energy Storage (TES) system. This TES system will target capturing and storing the waste heat generated during the intercooling process in a multi-stage air compression system. By effectively utilizing this currently wasted energy source, the project contributes to achieving the Vision's objectives of increasing energy efficiency and reducing dependence on conventional resources.

Abstract

Thermal energy storage (TES) systems are basically heat exchangers that store thermal energy for a given period of time and release it for use when required. The process of storing the energy is called charging and when this energy is released, the process is called discharging. In a multi-stage compression process, intercooling between the stages is employed to reduce the compressor power requirement. However, the heat of compression during the process is normally wasted to the surroundings. With rising costs of energy and the requirements of a cleaner environment, modern systems require that this energy be recovered and utilized in energy production. In this project a TES system is being designed for a compressed air energy storage system (CAES) that uses multistage compression for charging the system and multistage expansion in turbines during discharging. The design parameters of the TES system to be designed are obtained from a previously completed project on CAES. Several energy storage materials have been studied and evaluated in terms of their storage capacity, availability and cost and the best material has been selected for design. A preliminary design has been proposed and steady state design calculations have been performed.

Model

The thermal energy storage (TES) system depicted in the image is designed to store and release electricity using thermal energy. It consists of a thermal energy storage unit, a heat exchanger, and a thermal storage medium. The TES system operates by transferring heat from the thermal storage medium to the electricity grid through the heat exchanger. This allows the system to store excess thermal energy when it is available and release it when needed to meet the demand for electricity. The figure 1 provides a visual representation of the TES system, clearly showing the components involved and the flow of heat and electricity. It demonstrates how the TES system effectively stores thermal energy and contributes to a reliable and sustainable power supply.

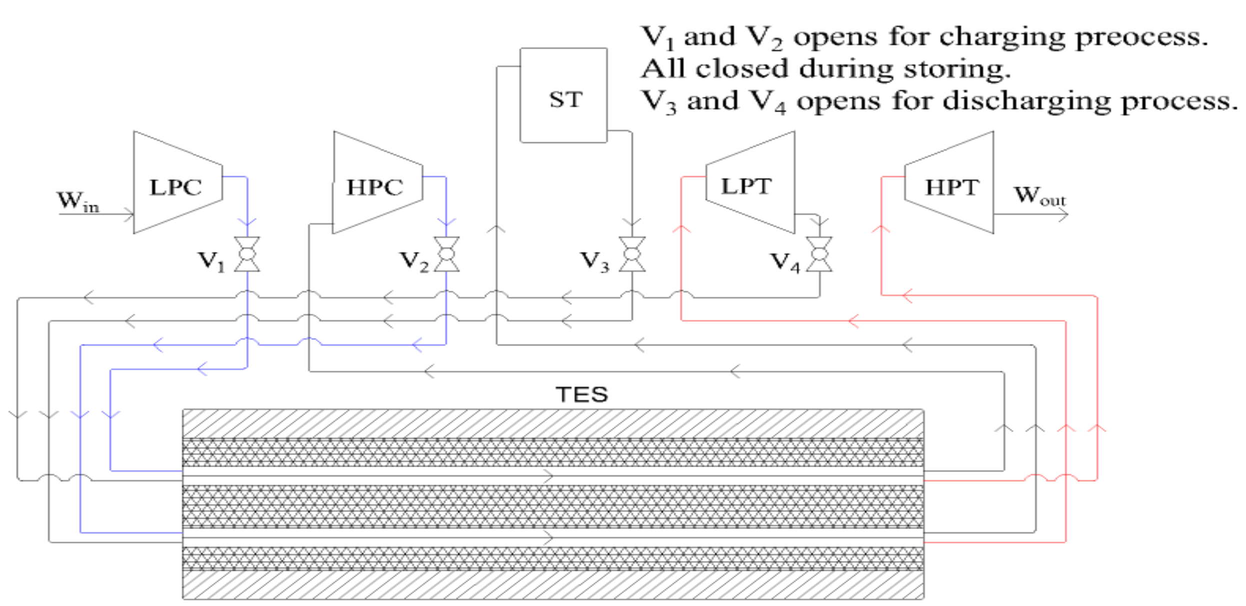

Figure 1: the TES within compressed air energy storage system for a wind turbine.

Simulation Results

The simulated three cases for the design of TES system for storing the heat from compressors in a multi-stage compression system with intercooling, with a simulation period up to 70 hours, and discharging the energy.

Design 1: Two-Pipes Thermal Energy Storage (TES) the length is 3.3m

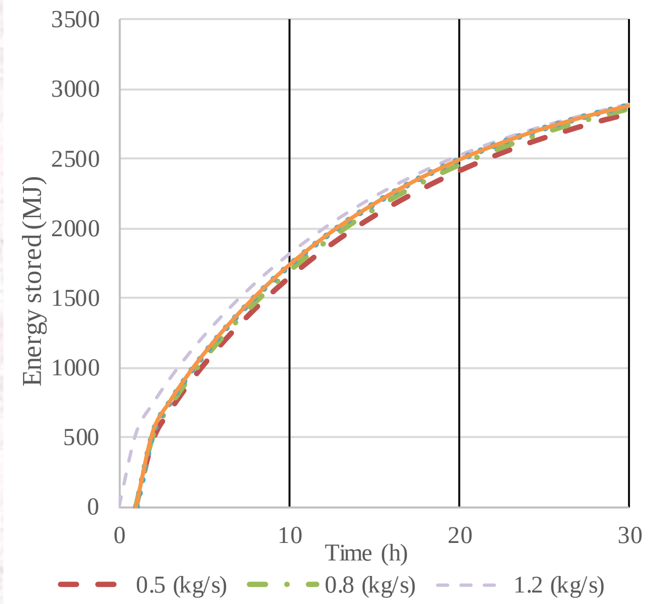

Figure 2: Energy stored vs time (Charging) different flow rates.

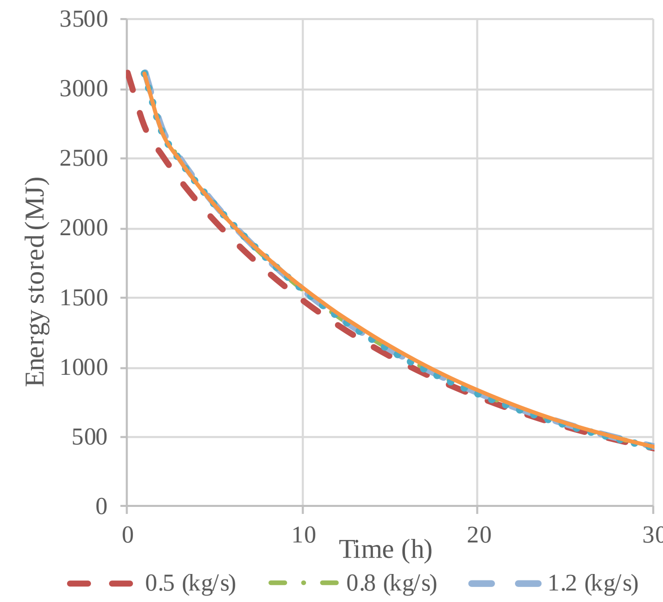

Figure 3: Energy stored vs time (discharging) different flow rates.

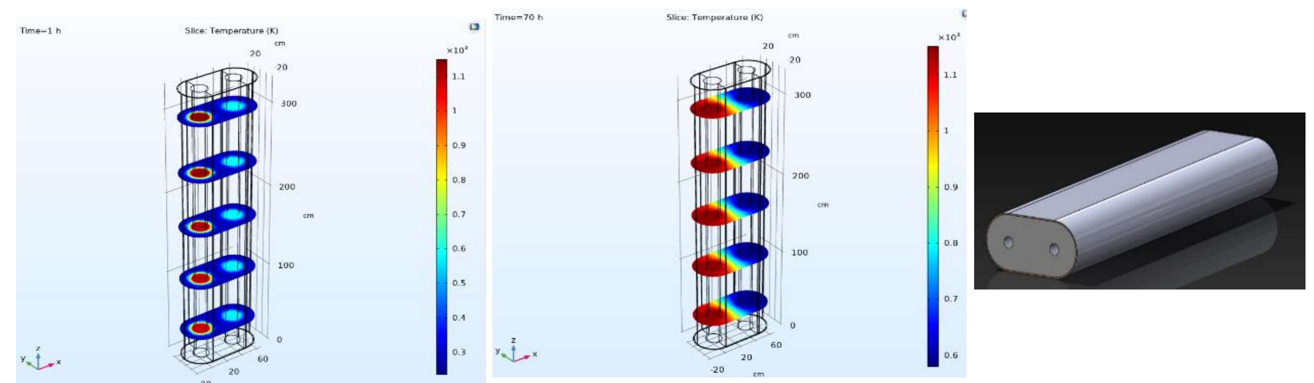

Figure 4: A final CAD for design 1. During charging operation.

Design 2: Multi-Tube Thermal Energy Storage (TES) The number of pipes is 128

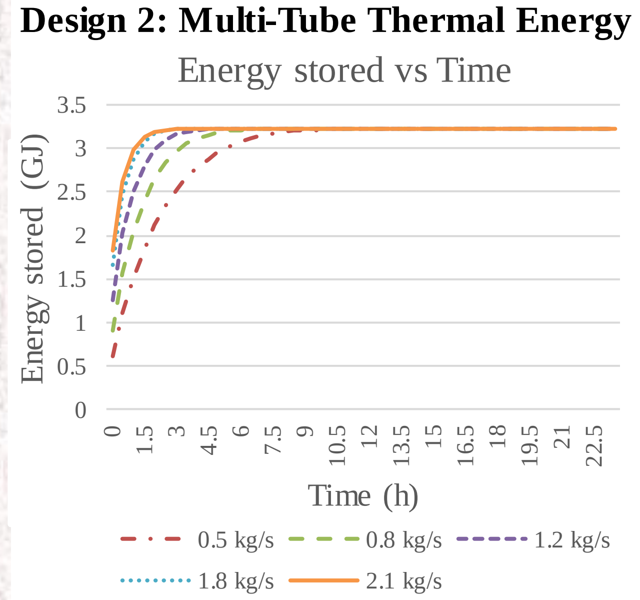

Figure 5: Energy stored vs time (Charging) different flow rates.

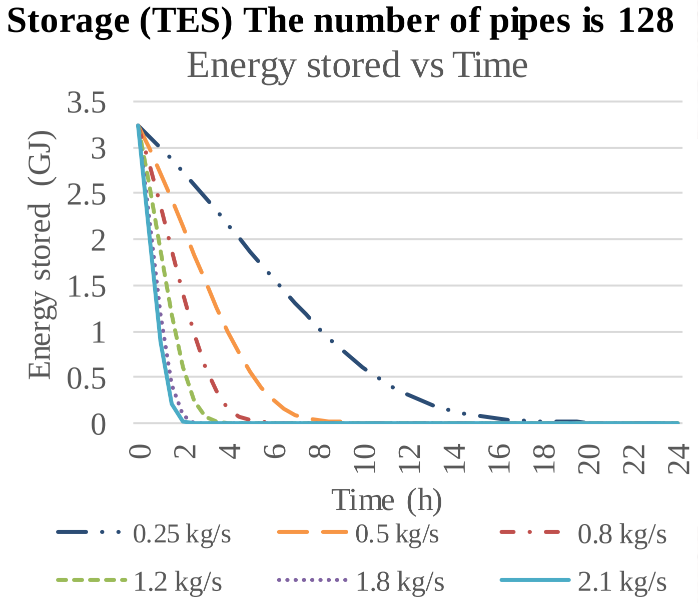

Figure 6: Energy stored vs time (discharging) different flow rates.

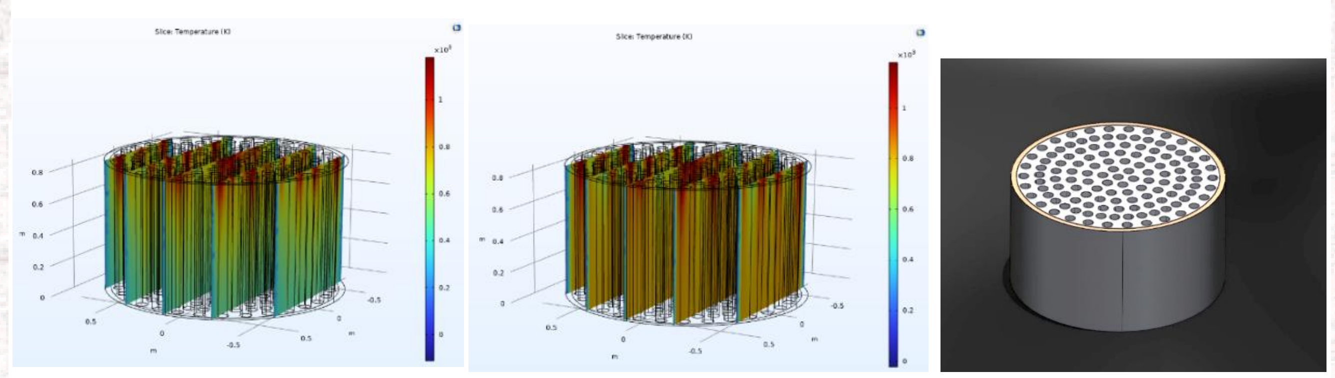

Figure 7: A final CAD for design 2. During charging operation.

Design 3: Multi-U-tubes Thermal Energy Storage (TES) 8 U-tubes

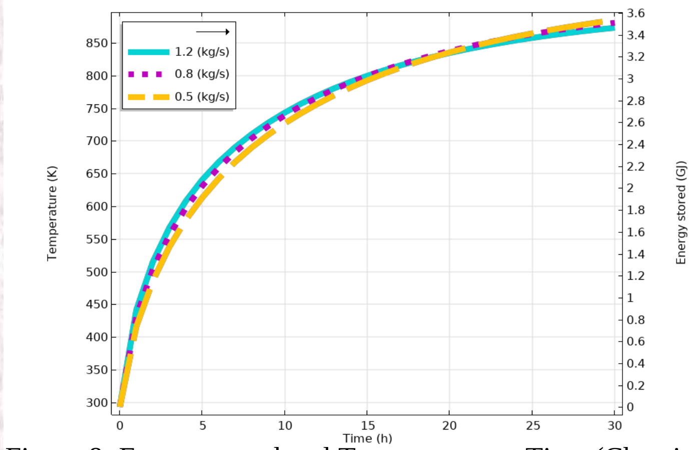

Figure 8: Energy stored and Temperature vs Time (Charging).

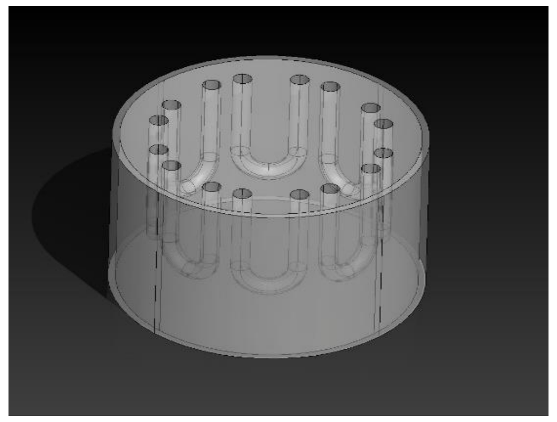

Figure 9: A final CAD for design 3.

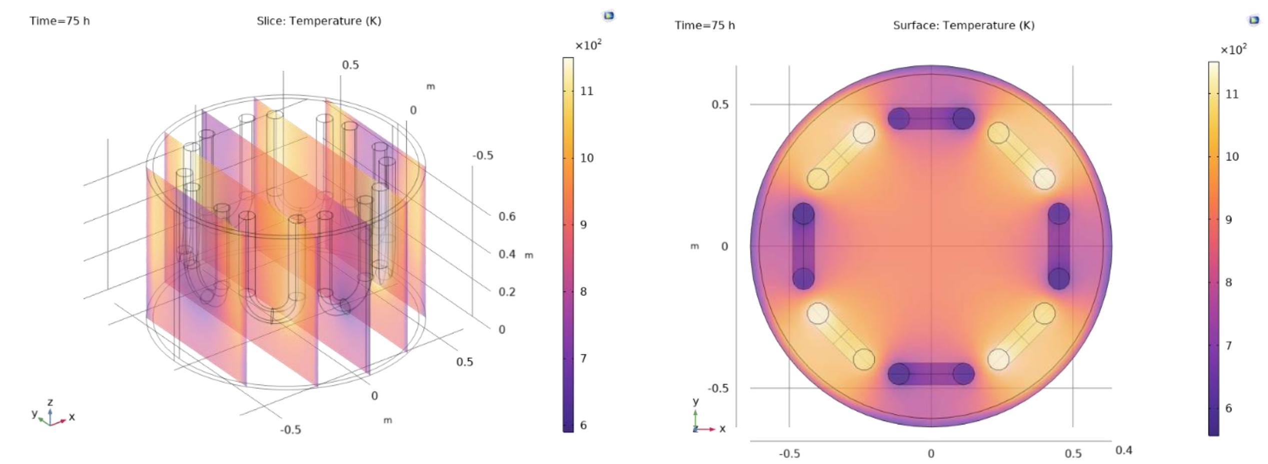

Figure 10: Design 3 during charging operation.

Table 1: price comparison between the designs

Design	Storing material mass (kg)	Insulation volume (m³)	Metal sheet volume (m³)	Total length pipes (m)	Total Cost (SAR)
Two pipes	2407.5	0.13	0.022	6.6	**1984.6**
Multi-Tubes	2506.3	0.039	0.0058	106.7	**22628.11**
Multi-U-tubes	2422.6	0.018	0.004	2.28	**644.92**

Conclusions

This project explored the design and simulation of a Thermal Energy Storage (TES) system for a multiple designs. Every design provided some positives and negatives.

Results summary:

- For flow rate 1.2 kg/s the designs have reached steady state temperature of 565 ℃
- The two-tube design provided a good price (1984.6 SAR) but a bad performance (reaches energy at steady state of 3.2GJ within 70 hours).
- The multi-tube design provided the most expensive design (22628.11 SAR) but the best performance (reaches energy at steady state of 3.2GJ within 8 hours).
- The multi-U-tubes design provided is a considerable option because its price is (644.92 SAR) and it preforms better than design 1 (reaches stored energy of 3.2GJ within 20 hours) note that this design competes with the 8 tube multi-tube design.

Key Findings:

- Flow rate, heat exchanging fluid, storing material and the geometry of the TES all can affect the operation and Performance of the TES
- Steady state analysis for designing a functional TES system is not enough, that is why we needed to apply Finite element method in transient state analysis for designing the TES.

Future Considerations:

- looking into the effect of alternative thermal storage materials with different heat storage capacities with faster thermal response times could further optimize system performance. but stores less heat.
- Developing control systems for the TES unit. to optimize the energy utilization according to demand.