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Steady State Modeling for the 10 Mwe sCO_2 Test Facility Program

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ABSTRACT

GTI Energy has been performing steady state and transient analysis using Aspen Plus and Flownex [1] to model the 10 MWe sCO_2 Brayton Cycle test facility being commissioned in Southwest Research Institute (SwRI) campus in San Antonio, Texas. Models were built for both the simple Brayton cycle and recompression Brayton cycle (RCBC) configurations that will be tested in the facility. The steady state models have been consistently updated to incorporate the latest data obtained from component vendors, ensuring their accuracy and relevance. This paper will review the results derived from the steady states models, and the results will be compared to the actual site test data that are scheduled for acquisition by February 2024.

INTRODUCTION

In the evolving landscape of power generation, the advancement and optimization of supercritical CO_2 (sCO_2) power cycles represent a significant step towards efficient and sustainable energy systems. Building upon the foundational work presented in "Dynamic Modeling for the 10 MWe sCO_2 Test Facility Program" [2], this paper shifts focus exclusively to steady state modeling which is a crucial aspect in the design and evaluation of sCO_2 power cycles. Steady state models are instrumental in providing vital input for equipment specifications, piping designs, and overall cycle performance, thereby guiding the control logic and methodology of power plants. In this paper, components within the sCO_2 cycle are modeled relying on vendor datasheets and operational constraints to ensure accuracy and reliability. Furthermore, this research extends its scope to evaluate various other sCO_2 cycle configurations and applications that aim to contribute significantly to the broader understanding and implementation of these systems in various energy sectors. The insights gained from this steady state modeling endeavor are poised to influence future designs and operational strategies of sCO_2 power plants.

The simple cycle model represents the fundamental layout of an sCO_2 power cycle, characterized by its straightforward design which encompasses a heater section, compressor, a heat recuperator, a turbine, and a cooler section. This model serves as the bedrock of sCO_2 cycle studies, providing a basic yet effective framework for understanding the core operations and efficiency potentials. It is particularly useful in initial stages of design and analysis that offers clear insights into the basic thermodynamic processes involved in the cycle.

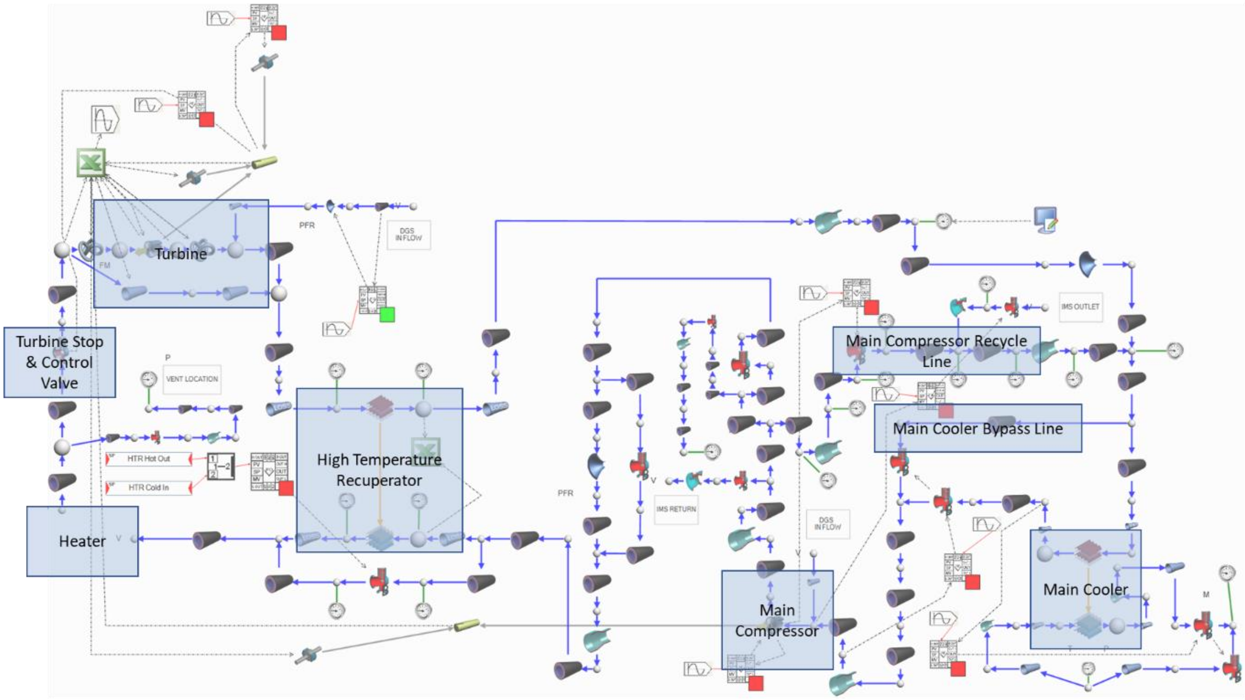

Figure 1. Flownex Model of Simple Cycle Configuration [2]

The RCBC model introduces a more complex configuration of the sCO_2 cycle. It includes a bypass compressor section, which enhances the thermal efficiency of the system by capturing and reusing a portion of the low-pressure, high-temperature CO_2 from the turbine exhaust. The geometrical specifications of components, as provided in vendor datasheets and within the bounds of operational constraints, have been integrated into the model. These modeling results have informed the development of the overall control logic and methodology. System-level validation of the model is planned by utilizing data gathered from the facility during its testing phase.

The commissioning schedule for the project has been outlined with key milestones set for the upcoming months. The compressor commissioning was completed in August 2023. Commissioning of the turbine and heater is scheduled to start in the week of November 13, continuing through December. The full system commissioning is anticipated to be finalized by the end of January 2024. All these dates are provisional and may be adjusted as the project progresses, to accommodate any unforeseen circumstances or requirements that may arise.

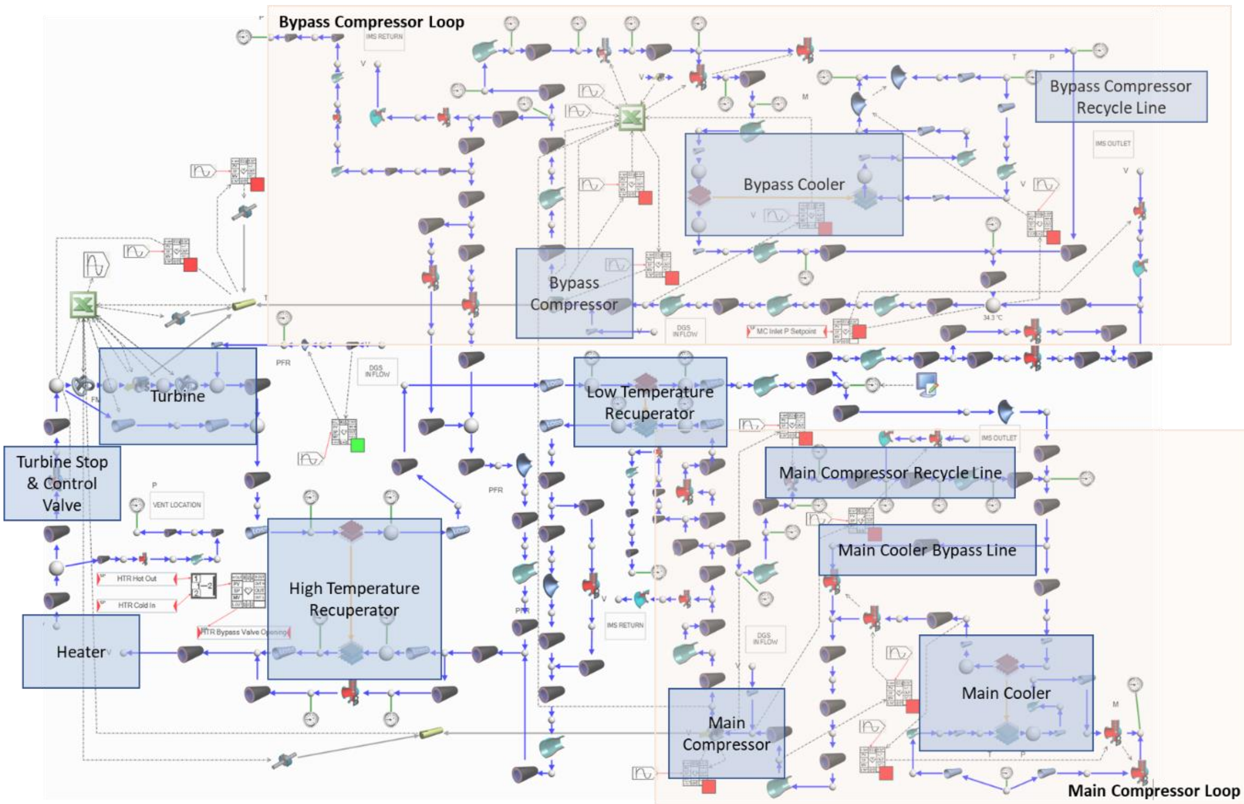

Figure 2. Flownex Model of Recompression Brayton Cycle Configuration [2]

RESULTS AND DISCUSSION

Table 1 presents the revised performance metrics for the 200 series simple cycle. In December 2022, a new set of main compressor maps was procured from Baker Hughes, accompanied by compressor test data acquired on October 18th, 2023. Subsequently, these maps were incorporated into the Flownex model, resulting in observed enhancements in both Net Power Output and Cycle Efficiencies across all simple cycle scenarios. Further analysis revealed that at an operational speed of 27,000 RPM, the main compressor's actual operating points for the maximum and minimum cases were located in the choke region (far right of the performance curve). To ensure operation within a safe and reasonable range, the decision was made to adjust the main compressor speed to 21,000 RPM.

Based on experiences from prior updates to compressor maps, it is necessary to maintain an up-to-date Flownex model with actual test data to ensure that operational parameters remain within reasonable bounds. Furthermore, an initiative is being implemented to establish a dedicated team responsible for the prompt acquisition of test data from the STEP test facility, thereby facilitating timely updates and refinements to the model.

Table 1. Flownex Steady State Model Performance Updates with New Compressor Maps

Model Names	Cycle Configuration	Description	Load %	Net Power Level	Cooler Exit Temperature	Turbine Inlet Temperature	Cycle Efficiency
233	Simple	Simple cycle minimum load case MC 21k RPM (2022)	Min	1.8 MWe	35 °C	500 °C	17.56%
236	Simple	Simple cycle maximum load case MC 21k RPM (2022)	Max	4.6 MWe	35 °C	500 °C	26.67%
230	Simple	Simple cycle minimum load case MC 27k RPM (2023)	Min	3.5 MWe	35 °C	500 °C	23.04%
N/A	Simple	Simple cycle maximum load case MC 27k RPM (2023)	Max	8.9 MWe	35 °C	500 °C	30.91%
251	Recompression	Baseline case	100%	10.0 MWe	35 °C	715 °C	43.21%
252	Recompression	“Hot” Day Case	70%	6.7 MWe	50 °C	690 °C	38.15%
254	Recompression	Partial load case using inventory control	40%	4.0 MWe	35 °C	685 °C	37.86%
255	Recompression	RCBC at 500°C turbine inlet temperature	75%	7.5 MWe	35 °C	500 °C	33.51%
257	Recompression	Partial load case using TSV throttling (transient condition)	40%	4.0 MWe	35 °C	715 °C	35.59%
257a	Recompression	Partial load case using TSV throttling	40%	4.0 MWe	35 °C	682 °C	35.18%

REFERENCES

[1] Flownex® version 8.2.0.1735

[2] Herrera, M., Heim, D. (2022) "Dynamic Modeling for the 10 MWe sCO_2 Test Facility Program", Proc. 7th International Symposium Supercritical CO_2 Power Cycles, San Antonio, TX.