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Off design performance of compressors of 150MWe S-CO_2 Cycle for Sodium Cooled Fast Reactor

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1. Background

Many research activities on sodium cooled fast reactor (SFR) concept have been performed by various research teams. Not only large scale SFR power plant concepts but also small modular SFR power plant concepts are considered as hot research issues.

KAIST research team also has been working on a SFR power plant concept. This research is more focused on small scale power plant and it adopts different concept which is coupling of supercritical CO_2 (S-CO_2) Brayton cycle to SFR.

Conventional SFR power plant concept utilizes steam Rankine cycle with intermediate heat transport loop. Thus, some difficulties of obtaining public acceptance are expected since active sodium water reaction can be considered as a major issue to the public. In this manner, KAIST research team suggested S-CO_2 Brayton cycle as an alternative power conversion system for SFR.

To apply S-CO_2 Brayton cycle to nuclear system, safety analysis for power conversion system should be performed for various postulated accident scenarios. Thus, off-design performances of each component are required. In this paper, efforts on turbomachinery off design performance prediction will be discussed.

2. Cycle description

KAIST research team works to develop improved concept of conventional SFR nuclear power plant. With the 150MWe target generating capacity and 505°C turbine inlet temperature, reactor core design, intermediate loop design, S-CO_2 Brayton cycle design have been conducted. According to the abovementioned top requirements, two different S-CO_2 Brayton cycles are designed by Ahn [1]. Among two different cycle layouts authors chose single shaft layout which is well-known recompression S-CO_2 Brayton cycle layout as shown in Figure 1 and turbomachinery operating conditions are described in Table 1.

Table 1. Turbomachinery inlet and outlet conditions of single shaft recompression cycle layout [1].

		Temperature, °C	Pressure, MPa
Turbine	**In**	505	19.9
	Out	405.8	7.6
Main Compressor	**In**	31.3	7.5
	Out	62.1	20
Recompression Compressor	**In**	66.4	7.5
	Out	160.5	19.9

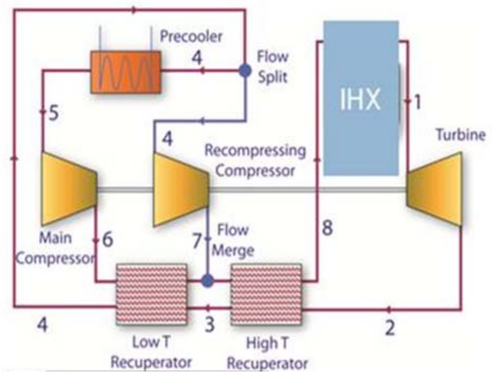

Figure 1. Single shaft recompression cycle layout

3. Turbomachinery performance prediction

Turbomachinery performance prediction can be divided into on-design performance and off-design performance.

Cycle condition calculation requires temperature and pressure conditions at every point on cycle layout and it can be calculated from component efficiency and top-tier requirements of the system. Thus, turbomachinery efficiency should be assumed and those are 80% for each turbomachinery, main compressor, recompression compressor and turbine. These efficiency assumptions can be verified through on design performance prediction.

During turbomachinery design and manufacture process, on-design conditions are utilized and all design parameters are selected for on-design conditions. Thus, if operating conditions depart from on-design condition turbomachinery performance should be revaluated for off-design condition. Off-design performance prediction is also important for system transient analysis. Nuclear power plants have high reliability and safety and it should be guaranteed by numerical analysis and experiment. As a part of numerical analysis, system transient analysis should be conducted on S-CO_2 Brayton cycle for various postulated reactor accident scenarios and off-design performance prediction is essential for the analysis.

However, conventional methodologies cannot be applied directly. Because CO_2 near the critical point doesn't have ideal behavior of thermodynamic properties so that correlations which are based on ideal gas assumptions cannot be used directly. Thus, authors constructed an in-house code KAIST_TMD which is a turbomachinery design and analysis code. KAIST_TMD was preliminarily verified with experiment data for radial compressor [2] and it was utilized for performance prediction. Since experiment data of component test with S-CO_2 working fluid is very limited, radial compressor module was preliminarily verified at first. Thus, results of radial compressor for 150MWe S-CO_2 power cycle are provided, Figure 2-5.

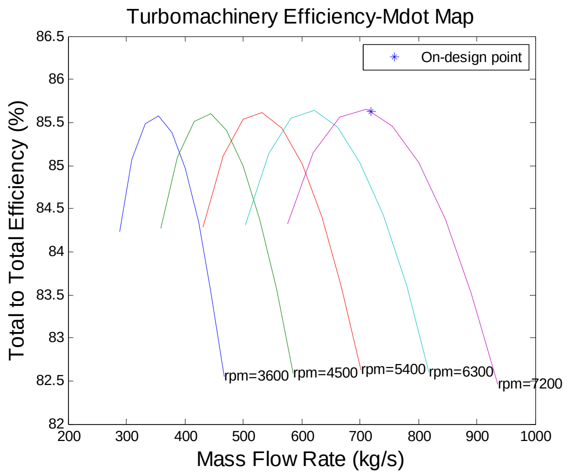

Figure 2. Efficiency prediction of main compressor

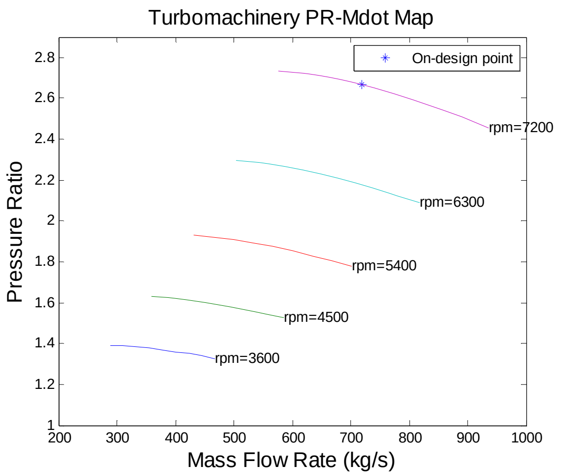

Figure 3. Pressure ratio prediction of main compressor

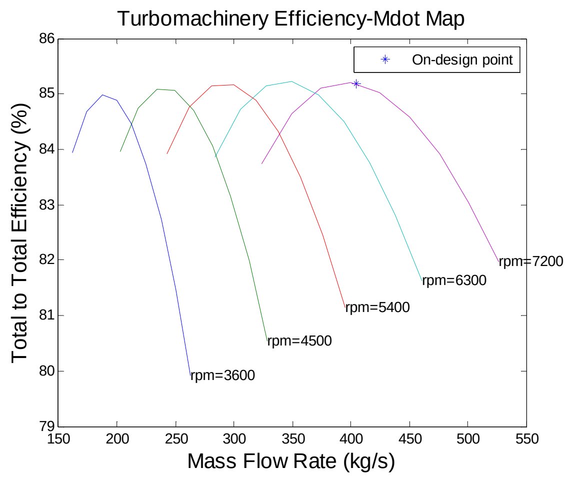

Figure 4. Efficiency prediction of recompression compressor

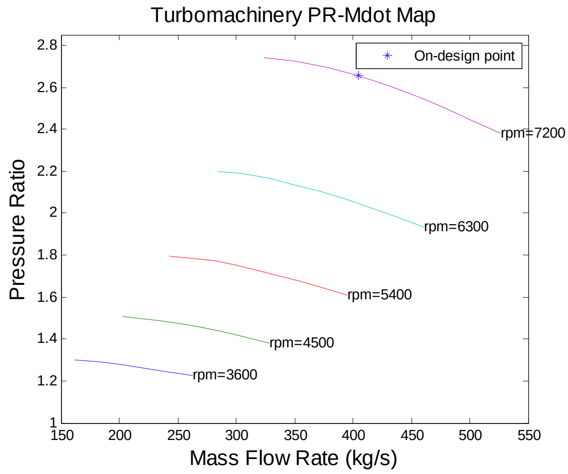

Figure 5. Pressure ratio prediction of recompression compressor

4. Summary and further works

KAIST_TMD successfully provided both of on-design and off-design performance prediction for S-CO_2 compressors of reference cycle described in [1]. Trend of off-design maps is acceptable and on-design performance prediction is also in reasonable agreement to efficiency assumptions for cycle calculation. 85% on-design efficiency of main compressor was predicted while efficiency of recompression compressor was estimated to be 85%.

As further works, KAIST_TMD will be verified with different experiment data sets for fine tuning and improved prediction accuracy. This code will be modified to couple with safety analysis codes in the future.

ACKNOWLEDGMENTS

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