Preliminary S-CO_2 Compressor Design for Micro Modular Reactor

Jekyoung Lee [a], Seong Kuk Cho [a], Seong Gu Kim [a], Jeong Ik Lee [a*],
[a]*Dept. Nuclear & Quantum Eng., KAIST, 373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea*
**Corresponding author : leejaeky85@kaist.ac.kr*

1. Background

Supercritical CO_2 (S-CO_2) Brayton cycle technology is currently considered as one of the important technologies for future energy market share due to its advanced economics. S-CO_2 near the critical point has abnormal thermodynamic property variation and it causes special thermodynamic behavior that S-CO_2 near the critical point has liquid like thermodynamic property. Since S-CO_2 near the critical point has liquid-like thermodynamic property, compression work is minimized for near the critical point condition and it enhance cycle performance which is directly connected to economics. Furthermore, component design can be compact since density of S-CO_2 near the critical point is competitive to the liquid.

Due to economic benefit of S-CO_2 Brayton cycle which is came from high efficiency and compactness, active research is currently conducted by various research groups and various approaches are suggested to take benefits of S-CO_2 Brayton cycle.

KAIST research team also has been working on advanced concept for application of S-CO_2 Brayton cycle to nuclear system and Micro Modular Reactor (MMR) concept was suggested [1].

In previous work done by Cho [2], conceptual compressor design was carried out. Thus, further preliminary design results for S-CO_2 compressor of MMR system will be discussed in this paper.

2. Cycle description

Basically, MMR accepts S-CO_2 Brayton cycle with direct cooling and complete modularization concepts as shown in Fig. 1.

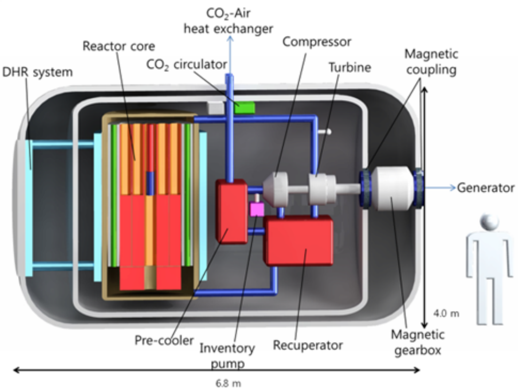

Fig. 1. Overview of MMR system

Thus, simple recuperated S-CO_2 Brayton cycle layout was accepted to minimize system volume for complete modularization. Another thing to be pointed out is that compressor inlet temperature of S-CO_2 Brayton cycle for MMR is not very close to the critical point of S-CO_2. Since MMR is aimed to multi-purpose usage with air-cooling system, system lower temperature should be increased to secure acceptable cooling capability.

Table 1. Summary of design result of S-CO_2 Brayton cycle for MMR

Thermal power	36.2MWth	Mass flow rates	175.69kg/s
Net electric power	12.0MWe	Thermal efficiency	33.86%
Generator efficiency	98%	Mechanical efficiency	98%
Compressor inlet pressure	7.50MPa	Pressure ratio	2.67
Rotating speed	20,200rpm	Compressor efficiency	85%
Turbine efficiency	92%	Recuperator effectiveness	95%
Design point of recuperator	Hot side inlet : 432.7℃, 7.58MPa Cold side inlet : 149.9℃, 20.0MPa Temperature difference : 22-58℃		

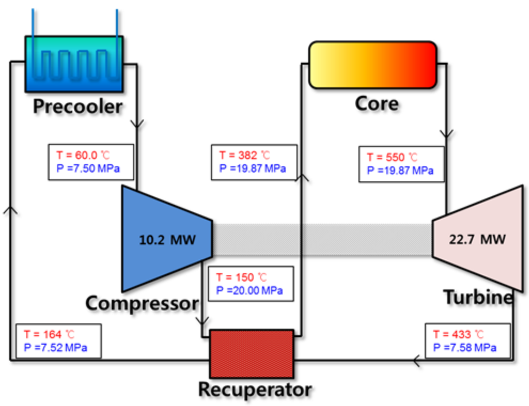

Fig. 2. Simple recuperated S-CO_2 Brayton cycle layout for MMR

3. Compressor design

From the previous work done by Cho [2], conceptual design for MMR system was provided. Thus, further preliminary design should be carried out to obtain feasible S-CO_2 compressor design for MMR system. KAIST_TMD [3] which is turbomachinery in-house code for real gases including S-CO_2 is continuously updated and currently it has 3D geometry construction and design optimization capability.

From the given cycle condition in Table 1 and Fig. 1, KAIST_TMD performed preliminary compressor design and main design results are described in Table 2.

Table 2. Main design results

Variable	Value
Stage pressure ratio	2.489
Total to total efficiency, %	71
Rotating speed, RPM	20200
Impeller inlet tip radius, mm	61.56
Impeller inlet hub radius, mm	15
Impeller outlet radius, mm	154.4
Impeller outlet blade height, mm	5
Vaneless diffuser radius ratio	1.9

Main observation on preliminary design results is that expected stage efficiency is lower than the result of conceptual design. It is because additional vaneless diffuser loss model is applied in updated KAIST_TMD and it lower stage efficiency than previous prediction. Since loss model validation is currently on going work, efficiency can be update in future.

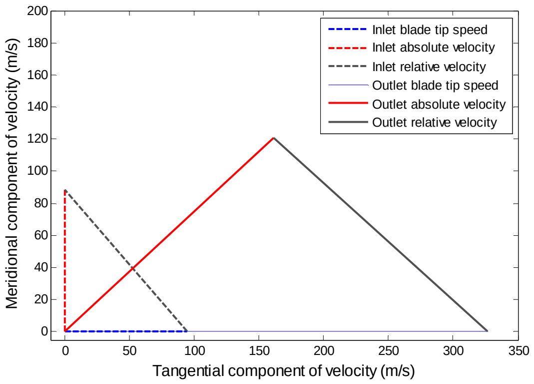

Fig. 3. Velocity triangle

Fig. 3 shows velocity triangle design result of MMR compressor. Inlet velocity triangle result which has 88 m/s of absolute velocity was designed by impeller inlet optimization principle. However, 88 m/s of absolute velocity can lead inlet static condition falls into gas state under given cycle total condition. Thus, iterative study with impeller design and cycle analysis should be followed to achieve reliable S-CO_2 Brayton cycle design for MMR system since different compressor inlet design will cause different compressor stage efficiency.

For outlet velocity triangle, impeller blade tip speed is around 326 m/s and it is due to high pressure ratio with single stage compression. In common practice, 300 m/s of impeller tip speed is allowable to use forged steel material [4] and S-CO_2 compressor for MMR system has little faster tip speed. Thus, it should be noticed that MMR compressor can have material consideration when it is manufactured.

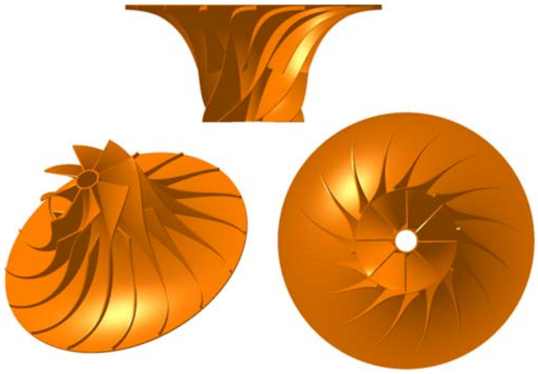

Fig. 4. Impeller design result

As a result, S-CO_2 compressor for MMR system is designed as shown in Fig. 4.

4. Summary and further works

The preliminary compressor design of S-CO_2 compressor for MMR system was carried out to observe feasibility of compressor design. Preliminary S-CO_2 compressor design for MMR system was successfully conducted and some issues are discovered from the design study.

As further works, iterative design study between cycle analysis and compressor design will be carried out for further update for following issues.

1. Compressor inlet design and compressor inlet cycle condition will be negotiated to secure compressor inlet static condition is on supercritical state
2. Update compressor performance should be updated to cycle performance prediction

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