Preliminary Design of Compressor Impeller for innovative Sodium Cooled Fast Reactor

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1. Introduction

Recently, S-CO_2 Brayton cycle technology is an emerging research area for power conversion system development due to attractive advantages of S-CO_2 Brayton cycle; high efficiency and compactness. Thus, various technologies and approaches are applied to component development and analysis or demonstration of the S-CO_2 Brayton cycle system. For nuclear power plant application, applying S-CO_2 Brayton cycle to Sodium cooled Fast Reactors and Small Modular Reactors are currently considered and active research is being performed by various research institutions and universities. As a part of research activities on the S-CO_2 Brayton cycle development for a nuclear power system, KAIST joint research team is currently working on an innovative Sodium cooled Fast Reactor (iSFR) development which utilizes S-CO_2 Brayton cycle as its power conversion system. Various research subjects including reactor physics, thermo-hydraulics, material, cycle analysis and system integration are being considered as research issues currently.

However, technical issues rising from dramatic change of thermodynamic property of CO_2 near the critical point still remain as problems to be solved. Among many issues on S-CO_2 component design and analysis, design and analysis methodologies of the main compressor is the most important issue since the main design concern of S-CO_2 Brayton cycle is to set operating condition of main compressor to approach the critical point. Thus, KAIST research is currently working on the construction of compressor design and analysis tool for S-CO_2 compressor which is called as KAIST_TMD to obtain reliable design and analysis results.

As a part of KAIST_TMD construction, 3D impeller geometry generation module was recently generated to connect between 1D mean stream line analysis and 3D CFD analysis.

2. KAIST_TMD

The main approach to develop KAIST_TMD which is turbomachinery design and analysis in-house code is the real gas approach. Ideal gas assumption based aerodynamic calculation doesn't guarantee a reliable calculation for CO_2 near the critical point due to peak region in thermodynamic property variation. Thus, applying enthalpy based calculation with thermodynamic property database REFPROP is accepted rather than ideal gas based calculation method.

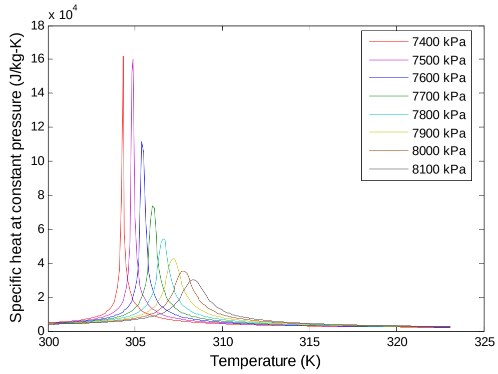

Fig. 1. Variation of specific heat at constant pressure near the critical point

KAIST_TMD was preliminarily validated with S-CO_2 compressor performance test data of Sandia National Laboratories (SNL) [1]. 5% of mismatch at design point is in reasonable agreement while off-design performance results were required to be improved [2]. Thus, 3D CFD method for detail analysis of fluid flow in impeller is required to improve performance prediction accuracy. So, impeller 3D model generation module was updated on KAIST_TMD to support 3D CFD analysis.

3. 1D Impeller Design

Compressor design procedure starts with compressor operating condition which is generally given condition from a cycle analysis. Impeller design was performed with 75MWe iSFR S-CO_2 Brayton cycle and the layout and operating conditions are shown in Fig. 2 and Table 1.

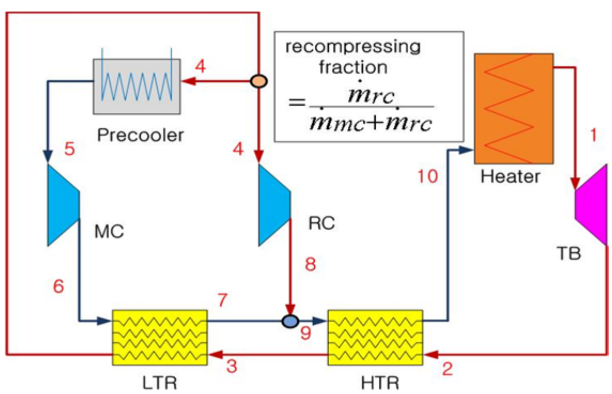

Fig. 2. iSFR S-CO_2 Brayton Cycle Layout, Recompression

Table 1. iSFR S-CO_2 Brayton Cycle State Points

	T (°C)	P (MPa)
Turbine inlet	505.00	19.88
HTR HS inlet	397.26	7.95
LTR HS inlet	213.66	7.80
Pre-cooler inlet	98.87	7.52
Main compressor inlet	32.18	7.5
Main compressor outlet	88.68	20
LTR CS outlet	208.31	19.97
Recompression compressor outlet	194.55	19.97
HTR CS inlet	203.30	19.97
IHX inlet	367.56	19.92

As a result, designed impeller has 567 mm of outer diameter with 7200 RPM of rotation speed and 84.7 % of isentropic efficiency at the design point. Detail design results and efficiency of off-design performance are shown in Table 2 and Fig. 3.

Table 2. Impeller Design Results

Impeller design results	
Inlet tip diameter, mm	280
Inlet hub diameter,mm	50
Outlet diameter, mm	567
Blade height, mm	24
Rotation speed, RPM	7200
Pressure ratio	2.7
Isentropic efficiency, %	84.7

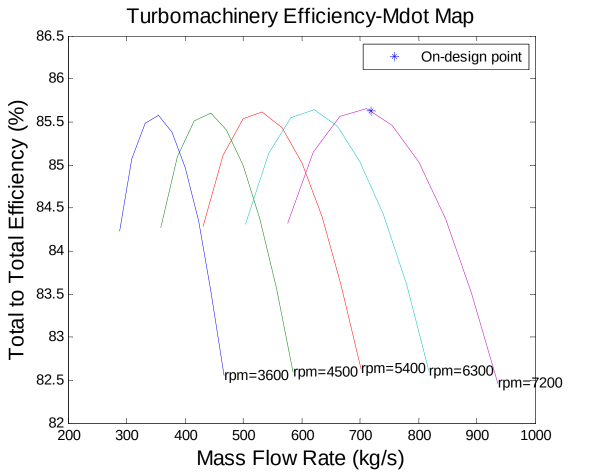

Fig. 3. Isentropic efficiency performance map of iSFR main compressor

4. Impeller 3D model generation

Design results in Table 2 are based on 1D mean stream line analysis, which internal impeller geometry calculation is not included in the design process. Thus, blade profile and surface profiles of impeller hub and tip are required for the impeller 3D model generation. The 3D model generation module calculates x-y-z coordination with given profiles and the profiles are referred from existing S-CO_2 compressor installed at SCIEL [3]. 3D model generation is basically geometric calculation along the revolution surface of hub and tip profiles. Blade profile information is projected on hub and tip revolution surfaces and the projection lines compose blade shape.

5. Results and Further Works

Fig. 4. 3D impeller model of iSFR S-CO_2 Compressor

As a result, 3D impeller model generation based on 1D mean stream line analysis results was successfully performed for non-airfoil blades. Since 3D model generation module works successfully, KAIST_TMD can support 3D CFD analysis for internal flow structure in the designed impeller. Compressor loss mechanisms are complex phenomena and these are difficulties to be modeled while considering each loss mechanism separately. Since the 1D compressor design and 3D impeller model generation platform was constructed by the work described in this paper, further loss model validation and blade shape analysis can be continued in further works.

ACKNOWLEDGMENT

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