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1D mean streamline Design Code Development for S-CO_2 Radial Inflow Turbine

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1. Introduction

The necessity of the next generation nuclear reactors has been constantly brought up because of the global warming, reusing the spent fuel, and enhancing the safety level. A supercritical CO_2 (S-CO_2) Brayton cycle has been considered as a promising candidate for those due to high thermal efficiency at relatively moderate turbine inlet temperature (450~650 ^oC), simple layout of power conversion unit, small component volume (i.e. turbomachineries and heat exchangers), and the mitigation of turbine blade erosion compared to the conventional steam power cycles [1]. Despite these benefits, some technical challenges (i.e. compressor operation near the critical point, elementary technologies for the turbomachinery, and system control strategies) still need to be solved for realizing the S-CO_2 Brayton cycle.

As part of such efforts, much research on the S-CO_2 compressor, including the system transient analysis and the integral loop experiment, has been performed. However, the number of studies of S-CO_2 turbine performance is very limited despite its importance. Thus, this paper deals with 1D mean streamline design code for the S-CO_2 radial turbine, namely KAIST-TMD. Also the developed design code attempts to generate the turbine performance map for the LP turbine in the Korea Atomic Energy Research Institute (KAERI) to validate the accuracy of KAIST-TMD in the future.

2. Methods

In this section loss models of KAIST-TMD and LP turbine of S-CO_2 Brayton Cycle Integral Experiment Loop (SCIEL) are described.

2.1 KAIST-TMD

Compared to the computational fluid dynamics (CFD) approach, the advantages of 1D mean streamline method are the simplicity of selecting the design parameters in the preliminary design stage and evaluating the design and off design performance by introducing empirical correlations, i.e. loss models. KAIST-TMD is a 1D turbomachinery design in-house code implemented in MATLAB environment and is integrated with NIST REFPROP to reflect real gas properties. It can predict the 2D radial turbine geometry and performance curves based on the given conditions.

As shown in Fig. 1, the design code considers inlet volute, nozzle, and impeller as main components during calculation. To minimize the kinetic energy loss at the impeller outlet, no swirl condition is adopted at the design condition. Also the flow pass blockage at trailing edge due to the boundary layer effect is not included in this code because the S-CO_2 turbine has high Reynolds number above 10^6. The implemented empirical models are summarized in Table I.

Even though it was developed for an S-CO_2 driven turbine, an indirect validation was conducted by comparing with the experimental data for air driven turbine in the previous research due to the absence of test data in S-CO_2 fields. The predicted results show a good agreement with the experimental data [2].

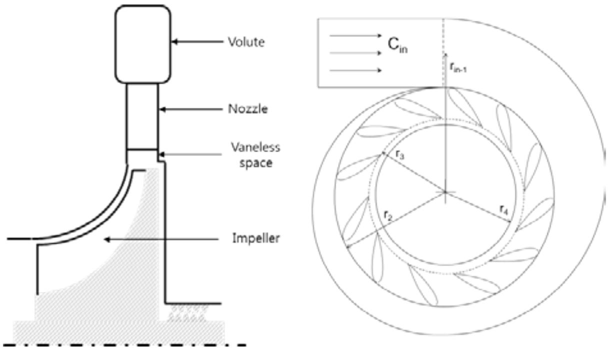

Fig. 1. Typical radial inflow turbine geometry [2]

Table I: Loss models of KAIST TMD - radial turbine module [2]

Category	Considered loss models
Volute	Circumferential distribution loss (Aungier)
Volute	Friction loss (Moody)
Nozzle	Static enthalpy loss (Benson)
Impeller	Incidence loss (Wasserbauer and Glassman)
Impeller	Rotor passage loss (Balje)
Impeller	Clearance loss (Jasen)
Impeller	Windage loss (Daily and Nece)

2.2 LP turbine for SCIEL

To accumulate operation experiences of a S-CO_2 Brayton cycle integral system and develop key elementary technologies, KAERI-KAIST-POSTECH joint research team has developed a few hundred kWe S-CO_2 Integral Experiment Loop (SCIEL). SCIEL has been constructed step by step, and currently the low pressure ratio electricity generation loop (2nd phase) has been built. It has a simple Brayton cycle layout and consists of a double suction low pressure compressor, a low pressure turbine (LP turbine), a pre-cooler, and an intermediate heat exchanger.

Turbomachineries were designed and developed by Jinsol turbo, a domestic vendor. S-CO_2 is known as having high hydrodynamic loading and high friction loss because it has a high fluid density and high Reynolds number over most of operating conditions. These characteristics cause not only generating irreversibilities in the turbomachineries but also significant heating at bearings [3]. To solve these issues, the turbomachineries in SCIEL adopt the shrouded impeller concept.

Fig. 2 shows the LP turbine assembly installed in SCIEL [4]. The main design parameters are summarized in Table II. While existing S-CO_2 turbines are installed as Turbo-Alternator-Compressor types, the turbine for SCIEL was designed independently. The design shaft speed of the turbine was selected as 80,000 rpm considering its physical limitations and turbine efficiency.

Fig. 2. LP turbine assembly installed in SCIEL [4]

Table II: Summary of LP turbine design and performance characteristics for SCIEL [5]

Design Characteristic	Value
Inlet total temperature	434.65 °C
Inlet total pressure	12,610 kPa
Pressure ratio	1.4938
Design mass flow rate	5.0526 kg/s
Design shaft speed	80,000 rpm
Total to total efficiency	85 %
Impeller inlet radius (r_2)	26.75 mm
Impeller outlet tip radius (r_4)	18.71 mm

3. Results

Fig. 3 shows the LP turbine performance map generated by KAIST-TMD. The total to total efficiency, 90%, is calculated. It is slightly higher than the designed efficiency.

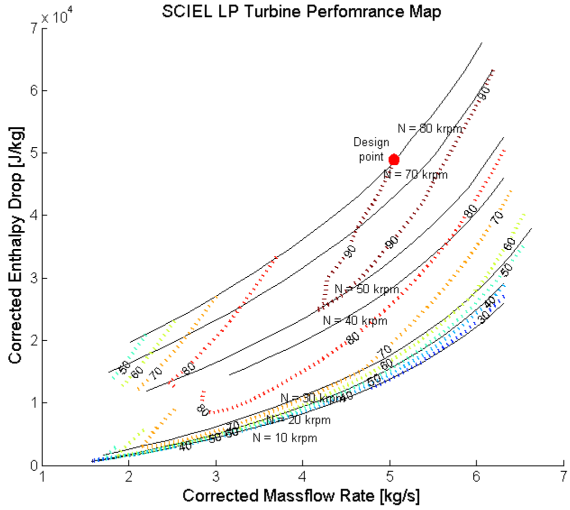

Fig. 3. LP turbine performance map predicted by KAIST-TMD

4. Summary and further works

A radial inflow turbine design code, namely KAIST-TMD, was developed on the basis of 1D mean streamline method and empirical correlations. This code can offer 2D radial turbine geometry and performance curves based on the given conditions. To validate this code, the performance map of the LP turbine in SCIEL was generated in this work.

As further works, the turbine performance tests will be conducted in S-CO_2 environment. Also, those data sets will be utilized to draw turbine characteristic curves and validate the design code.

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