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Computational Fluid Dynamics Analysis of Supercritical Carbon Dioxide Turbine

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1. Introduction

The supercritical carbon dioxide (SCO_2) gas turbine Brayton cycle has been not only adopted in the secondary loop of the Generation IV nuclear energy systems but also planned to be installed in the high efficiency power conversion cycles of the nuclear fusion reactors. The potential beneficiaries include the Korea Advanced Liquid Metal Reactor (KALIMER), Korea Superconducting Tokamak Advanced Research (KSTAR) and International Thermonuclear Experimental Reactor (ITER). The reason for these welcomed applications is that the cycle can achieve the overall energy conversion efficiency as high as 45%. The SCO_2 turbine efficiency is one of the major parameters affecting the overall Brayton cycle efficiency. Thus, optimal turbine design determines the economics of the Generation IV as well as the future nuclear fission and fusion energy industry.

Seoul National University has recently been working on the SCO_2 based Modular Optimized Brayton Integral System (MOBIS). MOBIS includes the Gas Advanced Turbine Operation Study (GATOS), the Loop Operating Brayton Optimization Study (LOBOS), the Nonsteady Operation Multidimensional Online Simulator (NOMOS), and the Turbine Advanced Compressor Operation Study (TACOS). This paper presents first results from GATOS.

2. Experiment

2.1 Input of SCO_2 Properties into CFX

CFX needs first be supplied with accurate SCO_2 thermophysical properties. The SCO_2 properties may be input to CFX via such method as a lookup table or a user defined mode. But these methods are difficult to use. As a result, the Redlich-Kwong properties were adopted [1, 2].

2.2 3D Modeling of Turbine Stator and Rotor

Computational analysis of SCO_2 flow around a turbine blade utilizing CFX has been performed to study the possible efficiency of the SCO_2 turbine as shown in Fig. 1. Typical characteristic curves for a SCO_2 turbine are presented in Fig. 2. This determines the basic design values like the blade and nozzle types, number of stages, blade height, and minimum and maximum radii of hub and tip. Basic design values of the turbine blade based on the Argonne National Laboratory design code was generated by ANSYS BladeGen™. The hub radius was 40 cm, and the tip radius was 46.5 cm. The blade height was 6.5 cm, and the mean radius was 43.5 m. Both angles of the camber inlet and outlet were 60°. The chord and leading edge were 8 and 0.1 cm long.

The boundary conditions were based on the secondary loop, i.e. the Brayton cycle [3, 4]. The inlet total pressure was 20 MPa at temperature of 823 K. The revolution of rotor was 60 per second. The average static pressure at the outlet was 17 MPa.

Figure 1. Rotor and blade of four stages gas turbine.

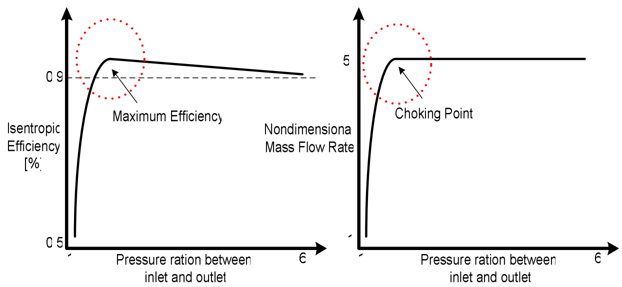

Figure 2. Characteristic Curve of optimal SCO_2 turbine.

3. Results

The first step in the computational analysis was to optimize simulation of the SCO_2 turbine with CFX. The simulation was found to concur with results calculated with the NIST code [2].

The second step was to find a high efficiency for the SCO_2 turbine. Computations were performed varying the angle of the camber.

4. Summary

An optimal SCO_2 turbine blade is developed for high efficiency of 90% by the computational analysis. The characteristic curve is analyzed to optimize the SCO_2 turbine for a high efficiency.

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