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CFD Analysis of a Supercritical Carbon Dioxide Compressor

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1. Introduction

The supercritical carbon dioxide Brayton cycle is considered as an attractive cycle for the next generation nuclear systems. It was identified that the compressor can achieve very small compressing work as operating conditions become closer to the critical point. Smaller amount of input work contributes to the enhancement of overall net cycle efficiency.

Comparing to traditional water-vapor cycle and helium cycle, the S-CO_2 cycle has relatively much less volume and component size. Therefore, S-CO_2 cycle can be used for many purposes such as nuclear ship propulsion where volume requirement is strict, or a small nuclear reactor when it is constructed on geographically limited area

One of the main factors for determining the supercritical Brayton cycle efficiency is the performance of turbomachineries. Many research organizations already obtained experimental data of S-CO_2 cycle turbomachineries, but the amount of data is still limited.

Our research team is conducting a S-CO_2 compressor test to obtain fundamental data for advanced compressor design and measure the performance of the compressor near the critical point. The S-CO_2 compressor testing loop is specially designed to test main compressor of the loop. The S-CO_2 fluid shows the properties of gases and liquids at the same time, but its behavior is closer to the liquid rather than gas near the critical point. Therefore, we are performing compressor test with canned motor pump which is unique from other previous studies.

2. CFD Analysis of S-CO_2compressor

2.1 Procedure of CFD Analysis

A 3D model of the impeller provided by the compressor manufacturer was utilized to perform CFD analysis. A commercial CFD tool for turbomachinery, CFX Turbogrid software was used for analysis. Fluid domain and grid was generated with Turbogrid software based on the provided geometry of impeller.

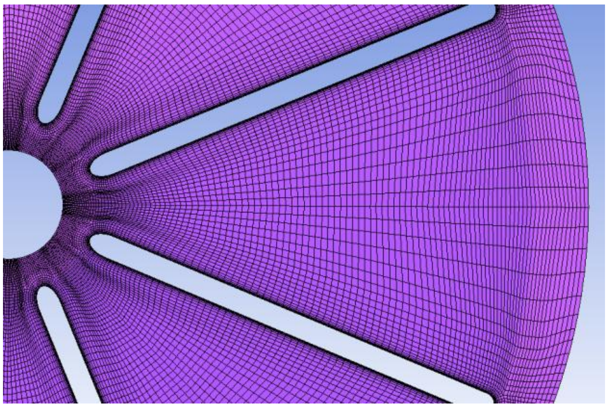

Fig. 1. Mesh of fluid domain in the impeller

The fluid domain is composed of 727,552 elements in 8 periodic passages containing 90,944 elements per blade. Periodic plane is placed in the center of blade-to-blade plane.

2.2 Properties of supercritical CO_2

To simulate unusual behavior of supercritical fluid in CFD, Redlich-kwong equation of state was used as property model. It is generally more accurate than the Van der Waals equation and ideal gas equation at temperatures above the critical temperature.

$$P = \frac{RT}{V_m - b} - \frac{a}{\sqrt{T}V_m(V_m + b)}$$
$$a = \frac{0.4275R^2T_c^{5/2}}{P_c}, b = \frac{0.08664RT_c}{P_c}$$

where Pc,Tc is the critical pressure and temperature.

Redlich-kwong equation of state predicts the density in close to the actual properties. Therefore, it represents an accurate flow characteristic curve. However, Redlich-kwong shows some inaccuracy on the properties related to the energy and momentum such as viscous force and enthalpy.

2.3 Boundary conditions

Boundary condition was set to be equal to the steady state operating conditions of compressor testing loop. The fluid state of the compressor inlet are 7.5MPa and 34℃ while the state of outlet is 0.5625kg/s per passage in mass flow rate. 8 blades of impeller rotates in counter clock wise 4620rpm.

3. Results

Total pressure plot shows gradually increasing value while static pressure increases relative slightly. It means mechanical energy of rotor is converted into dynamic pressure of fluid and added to the total pressure of fluid at the tip of blades.

From the experiments at the steady-state maximum output operation of 4620rpm, the outlet pressure of compressor was 8.9MPa and mass flow rate of outflow was 4.2kg/s.

The following values are obtained through the CFD result. Average value of total pressure at the outlet flow is 84.33bar. Mass flow rate of outflow is 5.002kg/s.

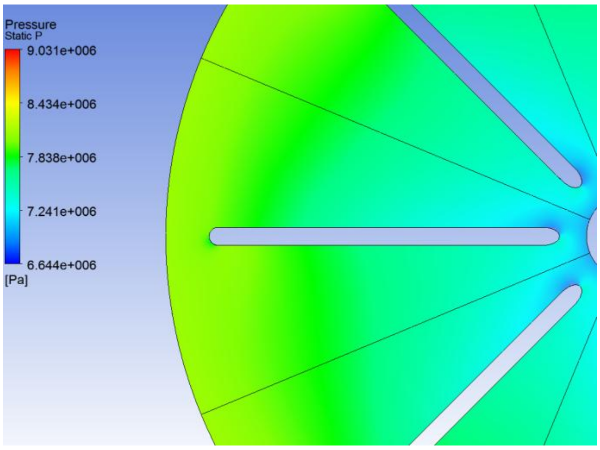

Fig.1. Plot result of static pressure.

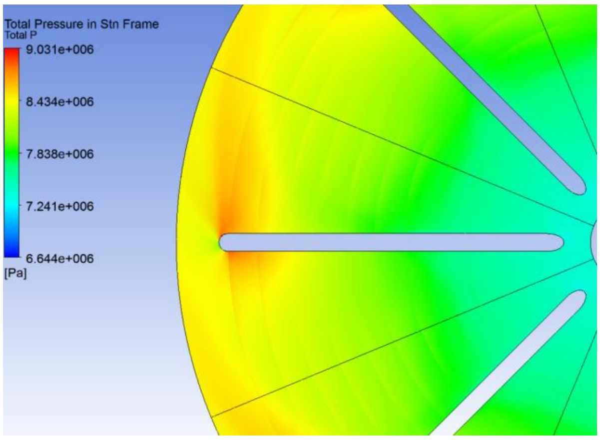

Fig. 2. Plot result of total pressure.

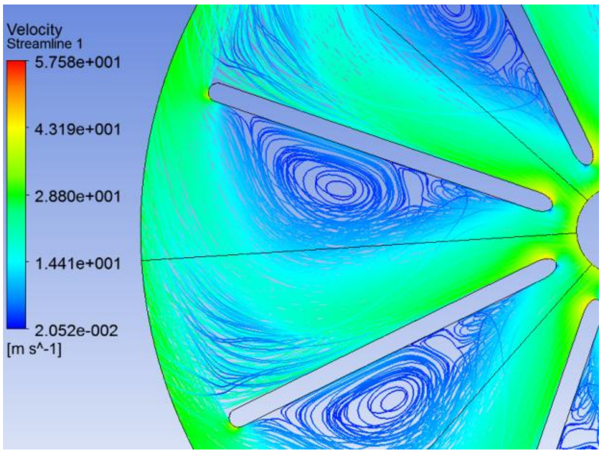

Fig. 3. Streamline of fluid through passage

4. Summary

CFD analysis data in this study was obtained from Redlich-kwong equation. This equation of state can accurately predict the total pressure gain and mass flow rate, but the computations of momentum and energy have less accuracy.

The results of this study are preliminary. It will be important for further study of CFD analysis of compressor including inflow pipe and outflow casing. In addition, we can get a more exact numerical value with the NIST properties using a user subroutine function. Then, the estimated efficiency and flow characteristic curves of compressor can be compared with the testing data. Also this CFD results will be used for designing an optimized impeller for advanced S-CO_2 compressor in the near future.

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