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Effect of CO_2 Purity on Performance and Optimum Point of Supercritical CO_2 Cycle

Seongmin Son [a], Jeong Ik Lee [a]*
[a]*Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology (KAIST)*
373-1 Guseong-dong, Yuseong-gu, Daejeon, 305-701, Korea
[*]*Corresponding author: jeongiklee@kaist.ac.kr*

1. Introduction

Supercritical CO_2 cycle (S-CO_2 Cycle) is a power cycle using CO_2 which supercritical phase as the working fluid. CO_2 exhibits high compressive performance near the critical point, and the S-CO_2 cycle has the advantage that the turbomachine size is smaller than conventional steam or gas turbines. Therefore, the S-CO_2 cycle is currently being applied in various fields, also there are many possible applications in future nuclear power fields such as SFR and SMR. [1]

The most of theoretical studies on the existing S-CO_2 cycle were carried out under the assumption that pure CO_2. In reality, however, it is impossible to maintain the perfect purity of CO_2. However, most studies on fluid mixing in the S-CO_2 cycle have been carried out for the purpose of suggesting a method for improving the performance. [2] Therefore, further study is needed to understand the adverse effects of impurity on performance.

This study quantitatively evaluated the effect of the typical impurities such as air and water vapor, on the cycle when they are involved in the working fluid. The effects were assessed on the basis of the S-CO_2 simple recuperated cycle (see Fig.1.). Moisture above the saturated water vapor content did not consider because it can harm the component. (In the real case, for this, the additional process would be required which removing liquid water.) The study is based on the NIST-REFPROP property database [3] in the traditionally considered S-CO_2 cycle condition. Table 1 shows the cycle conditions and component performances used in this study.

The research was done by analyzing the effect of moisture and dry air on cycle performance. Moisture was analyzed from 0 to 100% relative humidity and dry air was analyzed from 0 to 15 volume percent. Cycle analysis were performed using KAIST-CCD. [4]

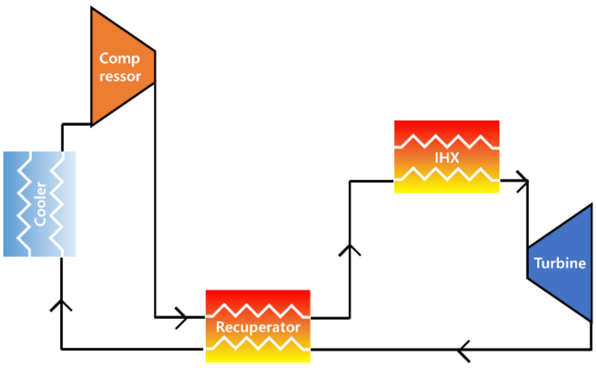

Fig.1. S-CO_2 Simple Recuperated Cycle Layout

Table 1: Description of analysis

	Value
Turbine Isentropic Efficiency (%)	90
Compressor Isentropic Efficiency (%)	80
Recuperator Effectiveness (%)	95
System Maximum Pressure (MPa)	25
Turbine Inlet Temperature (°C)	600
Cooler Outside Temperature (°C)	32
Component Pressure Drops (%)	Neglected

2. Methodology

The wetness is calculated using the saturated water vapor pressure under compressor inlet conditions. Since the vapor pressure of water at the inlet temperature of the compressor (32°C) is 4.7596 kPa, the volume fraction corresponding to the saturated water vapor pressure when the compressor inlet pressure is $P_{comp,in}$ kPa is shown in Eq (1).

$$\textit{Saturated water fraction} = \frac{475.96}{P_{comp,in}} \textit{volume}\ \% \ldots \mathbf{Eq\ (1)}$$

When the compressor inlet pressure is at the critical pressure (7410 kPa), the saturated water vapor fraction is 0.064%, which corresponds to 0.026% as the mass fraction.

In this study, the change of cycle performance is analyzed when the moisture content of CO_2 is 0 ~ 100% based on the relative humidity at the compressor inlet and when the dry air is mixed 0 ~ 15% of the volume fraction. The analysis proceeds in such a way as to observe the change of the optimum turbine pressure ratio and the change of the cycle thermal efficiency at that time.

3. Result

3.1 Influence of moisture on S-CO_2 cycle

Fig.2. shows the influence of moisture on S-CO_2 simple recuperated cycle at the 25 MPa of maximum pressure. As can be seen in Fig. 2, the moisture at which droplets are not formed at the compressor inlet has little effect on the cycle. Perfect dry condition and saturated water vapor conditions are only 0.15% in terms of optimal parameters and only 0.07%p in terms of optimum efficiency. This is because the fraction of water vapor initially allowed is extremely small (0.064 volume percent).

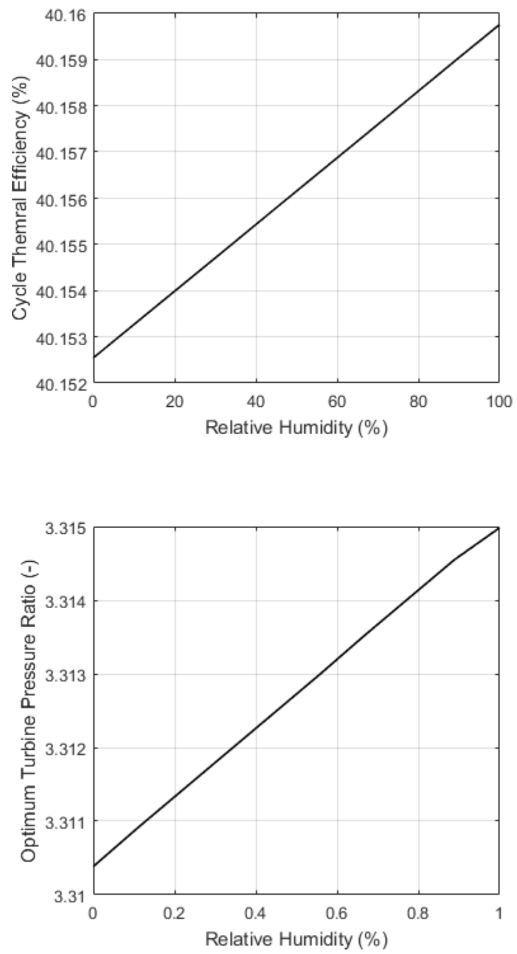

Fig.2. Influence of moisture on S-CO_2 simple recuperated cycle at the 25 MPa of maximum pressure (up) Optimum cycle efficiency along the relative humidity (down) Optimum Turbine Pressure Ratio along the relative humidity

3.2 Influence of air content on S-CO_2 cycle

Fig.3. shows the influence of air content on S-CO_2 simple recuperated cycle at the 25 MPa of maximum pressure. The air is assumed to be dry air. When 15% volume percent of dry air is included in the test case, the cycle efficiency is 1.4%p lower and the optimum pressure ratio is formed at 18.8% lower than pure S-CO_2 cycle case. The variation width tended to decrease as the air content increased.

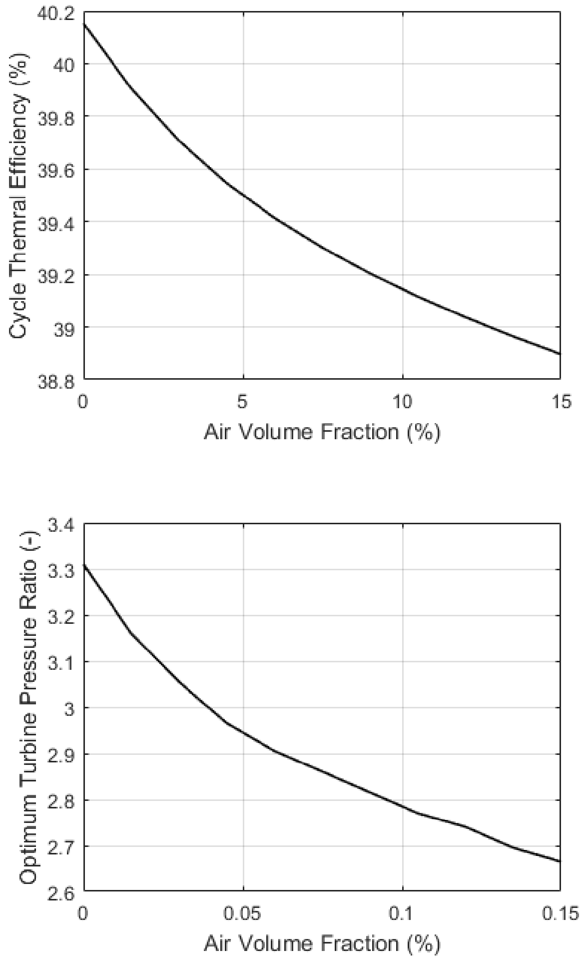

Fig.3. Influence of air content on S-CO_2 simple recuperated cycle at the 25 MPa of maximum pressure (up) Optimum cycle efficiency along the air volume fraction (down) Optimum Turbine Pressure Ratio along the air volume fraction

4. Conclusion

This study quantitatively analyzed the effect of purity of the working fluid, CO_2, on the performance of the S-CO_2 cycle from the viewpoint of the cycle. The estimated impurities are air and moisture. Moisture was interpreted only when liquid droplets were not formed at the lowest temperature compressor inlet condition. Under this condition, the amount of saturated water vapor is near 0.06% based on volume fraction and near 0.03% based on mass fraction. As a result of analysis, it is considered that this amount of moisture has little effect on cycle performance and optimum point. However, if there is more water than this, the effect of droplet should be considered from the component perspective.

Air content was analyzed up to 0-15% by volume fraction. Within the scope of the research, the cycle efficiency is 1.4%p lower and the optimum pressure ratio is formed at 18.8% lower than pure S-CO_2 cycle case. This result shows that the dry air content can have an effect on the optimum point even if it does not have a large influence on the cycle optimum efficiency. Particularly, the variation width was observed to increase as the amount of air content decreased. This result shows that the purity of the working fluid, CO_2, from a performance standpoint does not have to be very high, but it needs to be reflected from the design point of view.

ACKNOWLEDGEMENT

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