Transactions of the Korean Nuclear Society Spring Meeting
Gwangju, Korea, May 30-31, 2013

Effect of Uncertainties in CO_2 Property Databases on the S-CO_2 Compressor Performance

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1. Introduction

Nowadays, international and domestic research teams have been trying to develop a Supercritical carbon dioxide(S-CO_2) Brayton cycle technology. Thus, various S-CO_2 Brayton cycle experiment facilities are on the state of construction or operation for demonstration of the technology.

However, during the data analysis, S-CO_2 property databases are widely used to predict the performance and characteristics of S-CO_2 Brayton cycle. Thus, a reliable property database is very important before any experiment data analyses or calculation.

In this paper, deviation of two different property databases which are widely used for the data analysis will be identified by using three selected properties for comparison, C_p, density and enthalpy. Furthermore, effect of abovementioned deviation on the analysis of test data will be briefly discussed.

2. Property Databases

REFPROP which is the most popular property database is commonly used by S-CO_2 Brayton cycle research teams since it is convenient to use with various calculation codes. REFPROP calculates thermodynamic and transport properties. It implements three models for properties of pure fluids; equations of state explicit in Helmholtz energy, the modified Benedict-Webb-Rubin equation of state, and an extended corresponding states model [1].

Japanese research group PROPATH GROUP developed their own thermodynamic property databases PROPATH. Calculation in PROPATH is basically based on Bridgman's table since it can be derived by only 28 lines of formula for 336 different derivatives for thermodynamic property calculation [2].

3. Property Deviation Test

Our research team has our own S-CO_2 Brayton cycle pump test facility SCO2PE(Supercritical CO_2 Pump Experiment). During SCO2PE operation, authors had question regarding uncertainty of property database itself. The test data analysis, such as efficiency calculation and enthalpy prediction, depends heavily on the property database since temperature and pressure are the only measurements. Thus, uncertainty of property database can cause critical error of data analysis.

According to abovementioned motivation, Deviation between REFPROP and PROPATH was tested in the following steps

1. Determine temperature and pressure range
2. Call thermodynamic property such as C_p, density, enthalpy from each property database
3. Plot deviation between two property databases on z-axis as error

$$Error(\%) = \frac{REFPROP\ data - PROPATH\ data}{REFPROP\ data} \times 100(\%)$$

Figs.1-3 show result of the deviation test. Up to 2% of deviation exists near the saturation line and deviation increase was observed near the critical point. During the deviation test, unexpected high peak was observed. Authors carefully guess that there exists mismatch of phase boundaries between REFPROP and PROPATH.

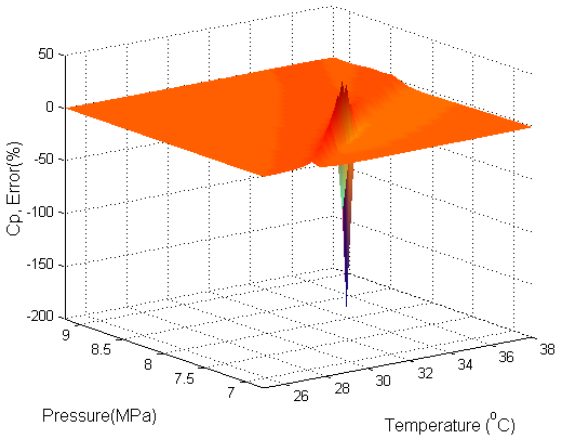

Fig.1. Cp deviation plot

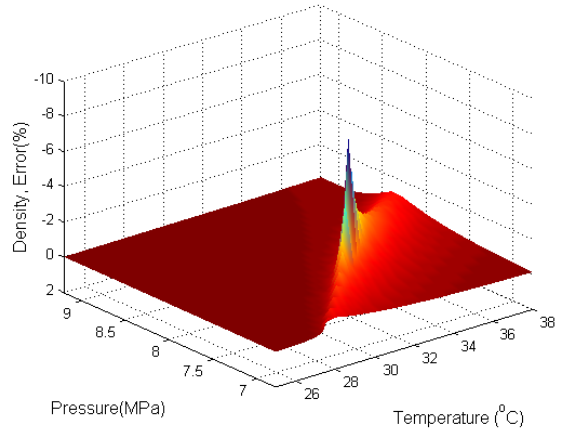

Fig.2. Density deviation plot

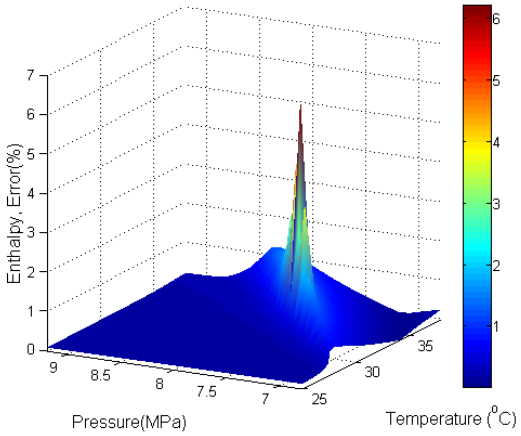

Fig.3. Enthalpy deviation plot

4. Effect of Property Deviation

To observe effect of property database uncertainty, extracted experiment data generated by SCO2PE operation is utilized with both property databases, REFPROP and PROPATH, for efficiency calculation. Two different sets of experiment data were selected. The first data set was taken at 37.6°C and 83bar pump inlet conditions while 40°C and 83bar were the pump inlet conditions for the second data set. When the abovementioned two different pump inlet conditions are plotted on enthalpy deviation plot shown in Fig.3, pump inlet conditions of first data set stays at higher deviation peak region which may result in deviation of efficiency calculation result.

Pump efficiency was calculated with different property databases. Higher deviation of the calculation result was observed with first data set, maximum 12% of efficiency deviation at 1.5kg/s mass flow rate case.

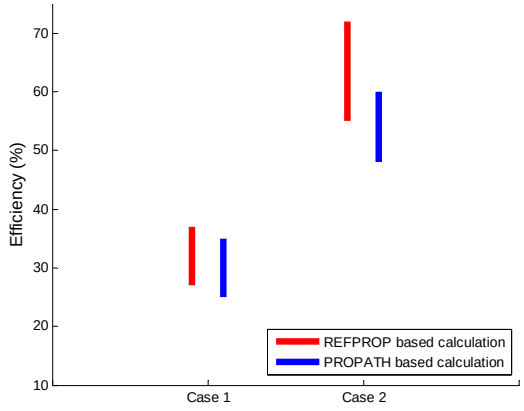

Fig.4. Difference of efficiency calculation result with first data set, (Case1 : case of 1kg/s mass flow rate, Case2 : case of 1.5kg/s mass flow rate)

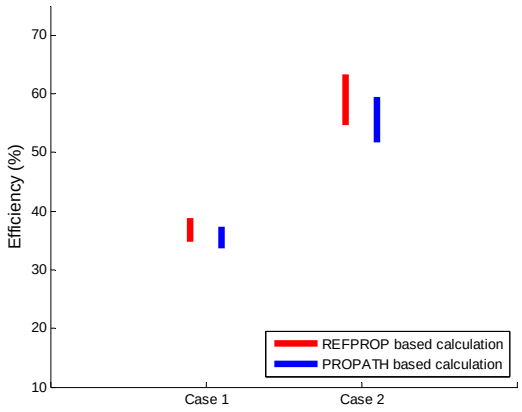

Fig.5. Difference of efficiency calculation result with second data set, (Case1 : case of 1kg/s mass flow rate, Case2 : case of 1.5kg/s mass flow rate)

Even pump inlet condition is stays away from high error peak, 2%~4% of calculate result deviation was observed with the second set of experiment data.

5. Conclusions

As a conclusion, it is clear that deviation of property database exists. From this deviation, results of the test data analysis can have critical error as shown in Fig.4 and Fig5. As the S-CO_2 Brayton cycle researcher knows, CO_2 near the critical point has dramatic change on thermodynamic properties. Thus, it is true that a potential error source of property prediction exists in CO_2 properties near the critical point.

During an experiment data analysis with the S-CO_2 Brayton cycle experiment facility, thermodynamic properties are always involved to predict the component performance and characteristics. Thus, construction or defining of precise CO_2 property database should be carried out to develop Korean S-CO_2 Brayton cycle technology.

ACKNOWLEDGMENTS

This research was supported by the National Research Foundation of Korea(NRF) and Sodium cooled Fast Reactor development Agency(SFRA).

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