THERMODYNAMIC PROPERTY MEASUREMENTS FOR SCO_2 MIXTURES RELEVANT TO ALLAM CYCLE

Dr. Suhyeon Park[1], Justin Urso[1], Dr. K. R. V (Raghu) Manikantachari[1], Prof. Subith S. Vasu[1]

[1]Center for Advanced Turbomachinery and Energy Research (CATER),
University of Central Florida, Orlando, FL 32816, subith@ucf.edu

Motivation

Direct fired sCO_2 cycles are promising for zero-emission future power generation systems. The working fluid of sCO_2 cycles will be near and above critical point of CO_2. One of the challenges is to use accurate equations of states and thermophysical properties for the simulations which models the real gas behavior of such mixtures.

Expected operating conditions of Allam cycles reach up to 300 bar and 1000°C. Mixtures in sCO_2 cycles may beyond the valid range of the widely used database such as NIST REFPROP. Experimental measurements of mixtures properties under extreme conditions are necessary to develop high-fidelity design tools for sCO_2 power cycles.

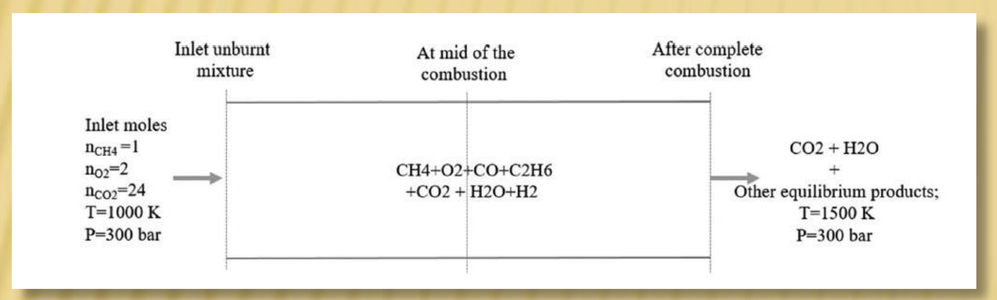

Figure 1: Schematic diagram to illustrate the mixture conditions considered

Aim of the current study:

In this study, density of various mixtures including CO_2, O_2, CH_4, H_2O is experimentally measured under different pressure and temperature conditions, and compared with NIST REFPROP database.

Method

Experimental setup

A temperature controlled portable high-pressure cell was used for density measurement. The cell can withstand pressure up to 4000 psi (276 bar). Manifold connection was removed at each measurements. A precision weight scale was used to measure the weight of the cell. Approximate internal volume of the cell was 80 ml. Fig. 2 shows the diagram of the experimental setup. Mixture compositions were selected to be close to frozen mixtures at the inlet and exhaust conditions of a model sCO_2 combustor in the previous numerical simulation work. Temperature and pressure conditions of experiments are 310-450K, and 0-150 bar.

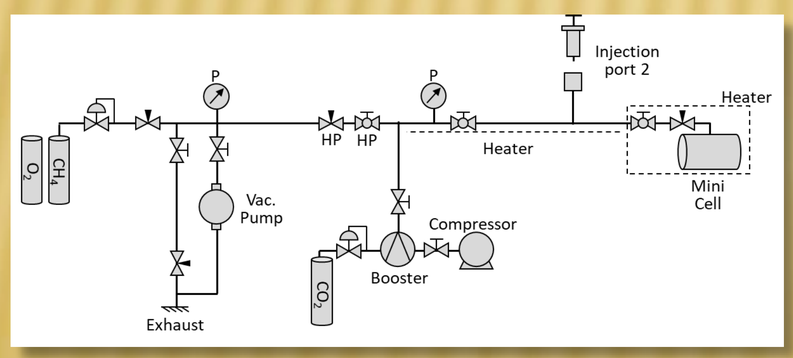

Figure 2: Experimental setup

Acknowledgements: This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under Award Number DE-SC0019640.001/C767.

Results

Validation and measurement uncertainty:

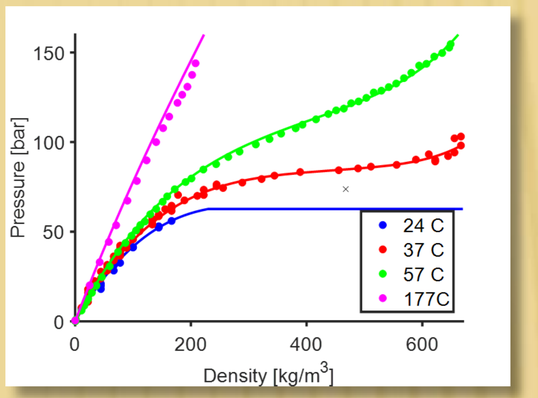

Figure 3: Measured density of pure CO_2

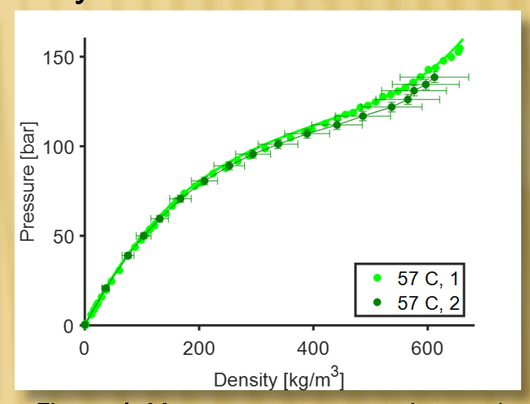

Figure 4: Measurement uncertainty and repeatability

Fig. 3 shows density measurement of pure CO_2 in good agreement with solid lines showing NIST REFPROP database. CO_2 is more compressed near critical condition. Two independent measurements of pure CO_2 at 57 C (330 K) are compared in Fig. 4. Error bars represent uncertainties of pressure and density.

- Pressure measurement: 1.4 %
- Density measurement: 1.68 kg/m^3
- Temperature measurement 2.2 K
- Overall uncertainty of density: 9.27%

Density of inlet mixture

Isothermal density of inlet ternary mixture (CH_4:O_2:CO_2 = 1:2:24) was measured at 6 temperature conditions. Fig. 5 shows density measurements of the inlet mixtures. Measurements agree well with REFPROP at pressures below 100 bar. At higher pressures, slight nonuniformity of temperature distribution inside the test cell may contribute to the deviation.

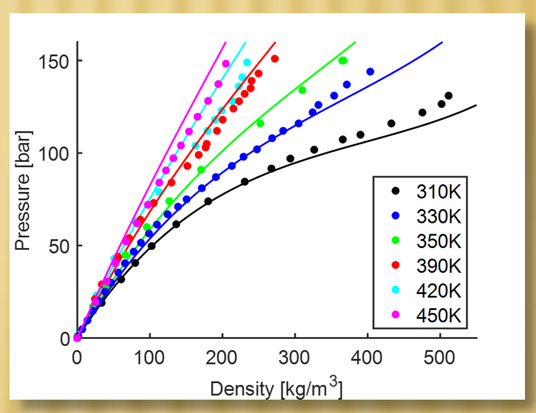

Figure 5: Measured density of inlet mixture in comparison with REFPROP

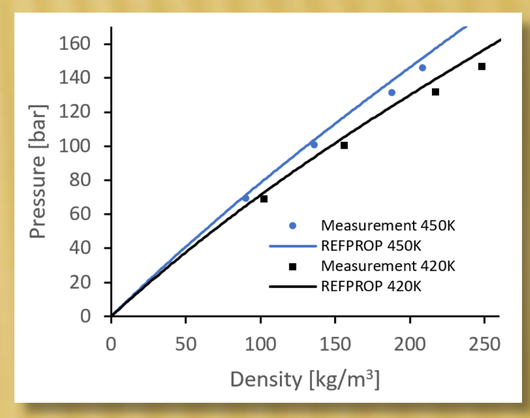

Figure 6: Measured density of exit mixture in comparison with REFPROP

Density of exit mixture

As a simplified exit composition, binary mixture with CO_2 and H_2O was used. Fig. 6 shows density measurements of the binary mixtures. H_2O mole fractions were 0.70% for 420 K data and 1.47% for 450 K data.

Conclusions

We measured density of Allam cycle relevant mixtures along isothermal curves at different temperatures. In our study, density from NIST REFPROP database agree with experimental measurements within the range of our measurement uncertainties.

Ongoing work

- We are extending the current measurements to higher temperatures and pressures using multiple experimental facilities.
- Validation of mixture rules will be carried out.

CATERing to the energy needs of society

UCF