

Corrosion of Structural Materials for Advanced Supercritical Carbon-Dioxide Brayton Cycle

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ABSTRACT

The supercritical carbon-dioxide Brayton cycle is being considered for power conversion systems for a number of nuclear reactor concepts, including the sodium fast reactor (SFR), fluoride salt-cooled high temperature reactor (FHR), and high temperature gas reactor (HTGR), and several types of small modular reactors (SMR). The supercritical carbon-dioxide (SC-CO₂) Brayton cycle provides higher efficiencies than the Rankine steam cycle due to less compression work stemming from higher SC-CO₂ densities, and allows for smaller component size and simpler cycle layout. The SC-CO₂ Brayton cycle also has a higher efficiency than the helium Brayton cycle, with the additional advantage of being able to operate at lower temperatures and higher pressures. Materials corrosion in high temperature SC-CO₂ will an important consideration in all of these applications, given their expected lifetimes of 20 years or greater. In fact, materials corrosion is regarded as one of the most significant gaps in the implementation of the SC-CO₂ Brayton cycle. The goal of the proposed research is to fill this critical gap by addressing key materials corrosion and related challenges, identify appropriate materials, and advance the body of scientific knowledge in the area of SC-CO₂ corrosion.

In the proposed research, corrosion behavior of a wide range of structural materials for components of the SC-CO₂ Brayton cycle will be studied, first using high purity CO₂ in the temperature range of 300°C to 750°C. The materials will be multi-component metallic alloys, simple model alloys, and a commercial form of silicon-carbide. Once corrosion in pure CO₂ has been studied, the role of impurities in CO₂ on corrosion, as well as the possible addition of inhibitor gas species to the CO₂ gas to mitigate corrosion, will be investigated. Fabrication of SC-CO₂ Brayton cycle components would involve materials joining processes. We will perform research on the solid state diffusion bonding process, which results in superior bond strength, and test the performance of these diffusion bonds in the SC-CO₂ environment. Stress corrosion cracking (SCC) of materials in the high temperature SC-CO₂ environment will be evaluated using ASTM C-ring tests to get a qualitative assessment of propensity for SCC of various candidate materials. Flow-assisted corrosion/erosion will be investigated using high velocity SC-CO₂ flow loops at the University of Wisconsin. Development of corrosion theories and modeling aimed at prediction of long-term corrosion will be the underlying theme throughout the project.

The project will be performed at the University of Wisconsin, but in active consultation with Sandia and Argonne National Laboratories – these laboratories are actively involved in the development of the SC-CO₂ Brayton cycle. Additionally, we will have an unpaid collaboration in the form of exchange of ideas and discussions with CEA, France, where good scientific research in the area of materials corrosion in SC-CO₂ environments has been performed.