348c Conceptual Design and Projected Performance for a Hybrid Sulfur Process

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A conceptual design for a Hybrid Sulfur (HyS) process for the centralized production of hydrogen (H2) using an advanced nuclear reactor heat source has been developed and an economic analysis carried out. The flowsheet was modeled, using Aspen Plus™, and material and energy balances were prepared from the simulation results. The presentation will describe this flowsheet, including unit operations and operating conditions, provide thermal efficiency estimates, and give an estimate of H2 production cost.

The DOE Office of Nuclear Energy, Science & Technology has established the Nuclear Hydrogen Initiative (NHI) to develop technologies that can be coupled with next generation nuclear reactors for H2 production. Thermochemical water-splitting cycles are leading contenders within the NHI program because they have the potential for high efficiencies with favorable scale-up characteristics.

Research programs world-wide recognize sulfur-based thermochemical cycles as high priority candidates for research and development. The NHI has identified the Sulfur-Iodine (SI) and HyS cycles as first priority baseline cycles. Both have potential for high thermal efficiency, and both have been demonstrated at the laboratory scale to confirm performance characteristics. The two cycles share a common, high temperature reaction step – the catalytic thermal decomposition of sulfuric acid (H2SO4).

The Savannah River National Laboratory (SRNL) has been tasked by the NHI with preparing a conceptual design of a HyS process powered by an advanced nuclear reactor heat source. SRNL has also been funded by the NHI to do bench-scale development of the SO2 anode depolarized electrolyzer that distinguishes the HyS from other sulfur cycles. The purpose of this presentation is to communicate the results of this effort to date.

A HyS flowsheet that includes three distinct sections was developed and modeled using Aspen Plus™. The first section incorporates the electrolyzers and their associated equipment. H2SO4 concentration and decomposition operations, which produce H2O and gaseous mixtures of SO2 and O2, make up the second section. Finally, the need to separate a clean O2 product stream from the SO2/O2 mixture coming from H2SO4 decomposition, and dissolve the remaining SO2 in the anolyte, leads to a third section where these tasks are accomplished. At present, energy utilization within the flowsheet is being optimized by means of Second Law analysis methods. The objective is to demonstrate a flowsheet that has a thermal efficiency in excess of 50% (higher heating value – HHV) basis.

The net thermal efficiency for the initial version of the HyS cycle was predicted to be 46.5%, assuming the use of heat from a 950°C gas-cooled nuclear reactor. This estimate is based on the HHV of the H2 product (285.8 kJ/mol) divided by the total thermal energy from the reactor, including the thermal energy needed to generate the requisite electric power (for the electrolyzer, compressors, and pumps). It should be noted that this efficiency is considerably higher than the estimated thermal efficiency for a low temperature, nuclear powered electrolysis plant, which is expected to be only 36% (HHV) maximum. Recent improvements in the flowsheet have pushed the estimated net thermal efficiency to 49.4% (HHV). Higher thermal efficiencies, exceeding 50% (HHV), are deemed feasible for the HyS cycle with further process flowsheet optimization and at increased reactor outlet temperatures. Preliminary estimates for the capital cost and the H2 production cost for an “Nth-of-a-kind” nuclear H2 production plant using the HyS cycle were calculated. The nuclear heat source design and cost prepared for a recent NERI study [1] using General Atomics Modular Helium Reactors and the SI thermochemical cycle were used as a cost basis. The cost of H2 production for the HyS Cycle nuclear H2 production plant was determined to be $1.64/kg at the plant gate for the baseline case. This cost was $1.94/kg for higher cost ($3,500/m2) electrolyzers and $1.44/kg for lower cost ($1,025/m2) electrolyzers. These costs are nearly the same as the H2 cost reported for the SI nuclear H2 production plant.

1. W.A. Summers et al., “Centralized Hydrogen Production from Nuclear Power: Infrastructure Analysis and Test-Case Design Study, Interim Project Report, Phase A Infrastructure Analysis”, US DOE NERI Topical Report, Project No. 02-160, 07/31/2004.