Development of Design and Simulation Models for Large-Scale Hydrogen Production Plants Using Nuclear Power

LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Sandia National Laboratories

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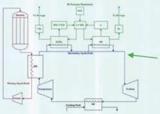
Problem Statement

Why Perform this Research?

The Department of Energy is expediting its search for economical, reliable fuel sources that produce minimal greenhouse gases. Among these are very high temperature reactors (VHTRs) suitable for large- scale production of H2 and electricity. The VHTRs are coupled to a secondary system and a thermochemical cycle. The sulfur iodine (SI) thermochemical cycle is a top choice due to its high efficiency. Analysis of a VHTR-SI system shows that each plant can produce about 420,000,000 kg H2/yr (at $1.38/kg, in situ) and generate close to 600 MW of electricity in the process.

Our Research…

Prior to this LDRD research, no single tool could simulate the fully-coupled VHTR-SI plant dynamically. Further, the SI chemistry could only be modeled in steady state. Our research extended the SNL/ NRC reactor code, MELCOR, in order to simulate the entire, fully-coupled system in transient mode. Furthermore, our transient SI chemistry models reproduced experimental data to mostly within < 5% error. The new tool is called MELCOR-H2, and it allows users to maximize H2 and electrical production, as well as enhance overall plant safety.



All components in this schematic of the VHTR-SI plant can now be modeled dynamically and fully coupled with a single MELCOR-H2 application.

Technical Approach

-Search the literature.

-Begin with MELCOR, a world-renowned reactor code being developed by SNL for the NRC.

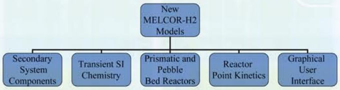
-Add key VHTR-SI Models: 1) reactor point kinetics, 2) transient SI chemistry, 3) graphical user interface (GUI), 4) reactor system models for pebble bed & prismatic core VHTRs, 5) turbines, compressors, intermediate heat exchangers, and generators.

-Validate and verify the models by comparing output with experimental data from the literature and known solutions. Model recent experiments from SNL & Japan (H_2SO_4 decomposition/SI cycle).

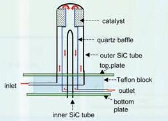
-Enhance the above models based on the above validation and verification process. Publish and present latest results at national and international conferences.

Summary of our LDRD technical research approach. The research spanned three SNL departments, three universities, and one contractor.

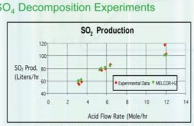
Key Results



Simulation of SNL H_2SO_4 Decomposition Experiments



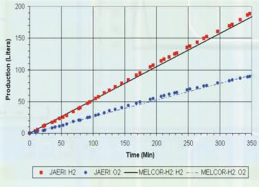
SNL sulfuric acid decomposition experiment.



Comparison between measured and calculated SO_2 production rates.

Simulation of the Japan Atomic Energy Research Institute (JAERI) SI Experiment

The calculated H2 production rate was about 30.9 l/hr, while the measured rate was 31.5 l/hr. In addition, the calculated O2 generation rate was half of the H2 generation rate, as expected.

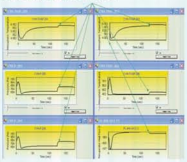


Turbine and Compressor Modeling, Graphical User Interface

MELCOR-H2 Turbine and Compressor Simulations vs JAEA Calculations.

Parameter	JAEA	MELCOR-H2
Compressor Exit Temperature (K)	410	409.4
Compressor Exit Pressure (MPa)	7.11	7.16
Compressor Work (MW)	251	253.6
Turbine Exit Temperature (K)	891	893.2
Turbine Exit Pressure (MPa)	3.68	3.62
Turbine Work (MW)	530	527.6

MELCOR-H2 computes transient variables and displays them on the screen in real time. The user may change input during a simulation to investigate system response.



VHTR Modeling

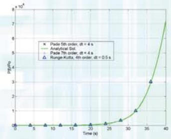
MELCOR-H2 input model of a Pebble Bed core.

MELCOR-H2 Output Comparison for a Steady-State Pebble Bed Reactor.

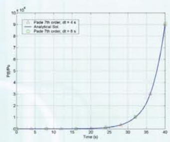
Parameter	MELCOR-H2	Literature
Helium Mass Flow Rate (kg/s)	130	129
Core Pressure Drop (MPa)	0.17	0.175
Helium Temperature Change through Core (K)	394	400
Maximum Fuel Temperature, Ring 2 (K)	1,330	1,373

Preliminary results are good, but additional models are needed, as noted in the recent thesis from Kevin Hogan. We are currently working on a prismatic core VHTR input model.

Point Kinetics Model—Reactivity Dynamic Response

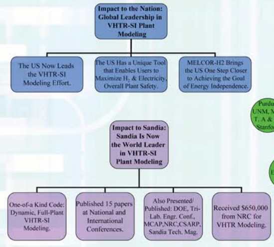


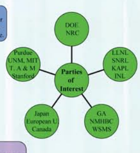
Comparison of MELCOR-H2 Padé point kinetics models with the exact Inhour solution for the case of $1.0 step reactivity insertion ($\Lambda = 10^{-2}$ s).



Effect of time step size on accuracy of the MELCOR-H2 point kinetics model for the case of $1.0 step reactivity insertion.

Significance





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