Idaho National Engineering and Environmental Laboratory

Assessment of a Molecular Diffusion Model in RELAP5-3D

Cliff B. Davis, Larry J. Siefken, and Chang Oh
Outline

• Introduction
• RELAP5 diffusion model
• Japanese inverted U-tube experiment
• Assessment results
• Conclusions
• Future work
Introduction

• The core flow may stagnate following a LOCA in the VHTGR due to non-uniform concentrations of helium and air

• Molecular diffusion will act to make the concentrations of helium and air uniform and establish natural circulation

• Natural circulation leads to air ingress into the core that results in graphite oxidation, which increases peak cladding temperature and is thus of concern
RELAP5-3D is being improved to support analysis of VHTGRs

• Models have been previously added to the code
  – CO, CO$_2$, and O$_2$ noncondensible gases
  – Graphite oxidation models for air ingress

• A molecular diffusion model has been added to an experimental version of the code
  – The model has not yet been incorporated into the mainline version of the code
A molecular diffusion model has been added to the code: (1/2)

• The molecular diffusion model is based on Fick’s second law for spatially uniform pressure and temperature

• Binary diffusion coefficients are obtained from the correlation of Fuller et al.*

• The model currently assumes binary diffusion and a simply connected nodalization

A molecular diffusion model has been added to the code: (1/2)

- Assessments have been completed using data from a Japanese inverted U-tube experiment, which is the subject of this presentation

Inverted U-tube apparatus*

- Contains U-tube, ball valves, and tank
- U-tube initially contains He, tank contains N₂
- Temperature controlled by heaters and water jacket
**Two tests were conducted**

- Mole fraction of nitrogen was measured as a function of time
- Tests were initiated by opening the ball valves
- An isothermal test at room temperature
  - Molecular diffusion was the dominant effect
- A non-isothermal test with temperatures varying between 19 and 256°C in the “hot” vertical leg and between 18 and 124°C in the “cold” vertical leg
  - Molecular diffusion and convection were both important
A RELAP5 model of the inverted U-tube was constructed

- Model much more detailed than typical reactor models (144 control volumes, most 2.45 cm long)
- Heat structure outer surface temperature set at measured value
- Tank divided into two halves
**RELAP5 results were in reasonable agreement for the isothermal test**

- $\text{N}_2$ mole fraction increased symmetrically in both legs
- Calculation slightly outside uncertainty band at lowest elevation, better at upper elevations
Results slightly better with increased nodalization

- The number of control volumes was doubled with the detailed nodalization.
Similar results were obtained for the heated experiment

- Mole fraction increased more rapidly in hot leg because of higher diffusion coefficient and buoyancy effects
- Rapid increase near 220 min was caused by onset of natural circulation
- Timing of onset well predicted
Better comparisons were obtained at higher elevations
Better results were obtained at higher elevations

\[ z = 1.35 \text{ m} \]
Conclusions

• The RELAP5 results were in reasonable agreement with the data from the Japanese inverted U-tube experiment
  – Important trends were replicated
  – Timing of the onset of natural circulation was predicted well

• Results not expected to be as accurate using typical reactor nodalizations, but should show trends
Future work

• Comparisons with additional diffusion experiments
  – Preliminary results in poor agreement with the Japanese HTTR scaled experiment
  – Preliminary results obtained for the NACOK facility are qualitatively similar to those predicted by German researchers
  – Additional work required

• Generalization of the diffusion model to allow:
  – Five species
  – Complex nodalizations (with branching) that are representative of reactor models

• Comparisons with NACOK pressure drop experiments