Preliminary Simulation of the Sodium Thermal Energy Storage Verification Test Facility with Modelica

Yong-Hoon Shin, Jung Yoon, Hyeonil Kim, Jewhan Lee

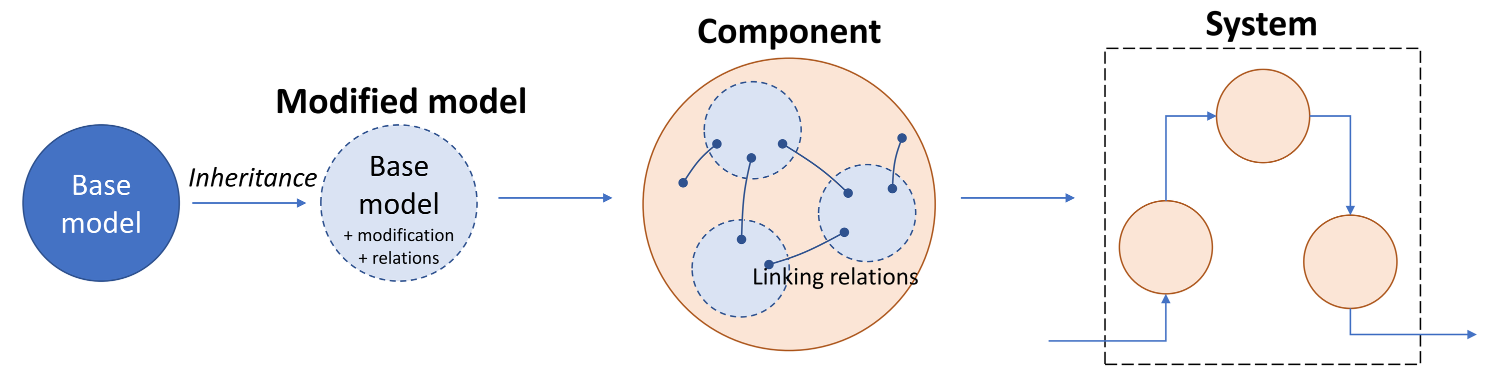
yshin@kaeri.re.kr; Korea Atomic Energy Research Institute, Versatile Reactor Technology Development Division, 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon

Introduction

- The growing market share of renewables leads to a great challenge for the electric grid to deal with their innate intermittency. The most known solution is energy storage systems (ESS) in diverse forms storing energy that can be drawn out with ease or transformed into electricity. Among others, the thermal energy storage (TES) systems are basically heat reservoirs that can hold heat for a while with a limited energy loss, and that distribute the stored energy in response to demands.
- The near-zero carbon footprint of nuclear powerplants drives interests in developing **nuclear-renewable hybrid energy systems (NRHES)**, which encompass various arrangements of coupling between nuclear and renewables. **Sodium can be an attractive alternative heat storage medium for a TES system** as a subsystem or a subcomponent in an NRHES, with its high boiling point enabling elevated temperature applications and material compatibility assuring cost-effectiveness compared to conventional molten-salt-based TES systems.
- As part of the study, we are designing **a sodium TES verification test facility** to experimentally investigate its applicability. In support of the experimental work, this study focuses on developing models to be used for the simulation of the test facility based on the **Modelica language**. The model can help design the facility from early stages by providing expected behaviors under specific design requirements, and finally contribute to minimize any kinds of trial errors. Furthermore, the simulation data are expected to be compared to test results and this comparison will be utilized on its upscaling.

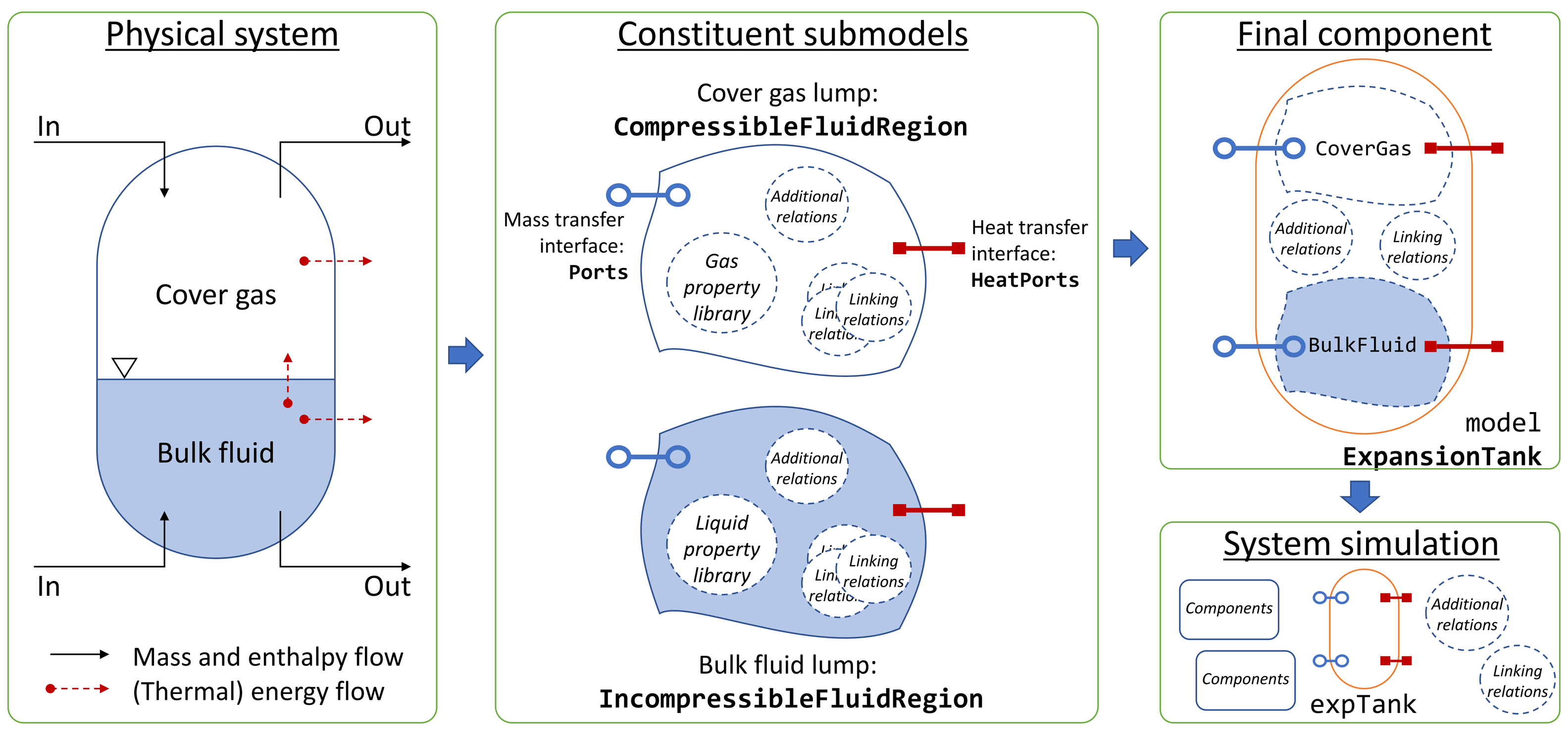
Numerical model development

Problem definition/ System of interest	A two-tank TES system with hot (700 °C) and cold (200 °C) sodium tanks accommodating max. ~ 7000 kg
Development environment	• Language: Modelica Version 3.2.3 • Compiler: OpenModelica Version 1.19.0
Modeling strategy	• High-level language: governing equations in forms of differential and algebraic equations • Object-oriented programming: extension and expansion through inheritance and redeclaration of pre-defined models



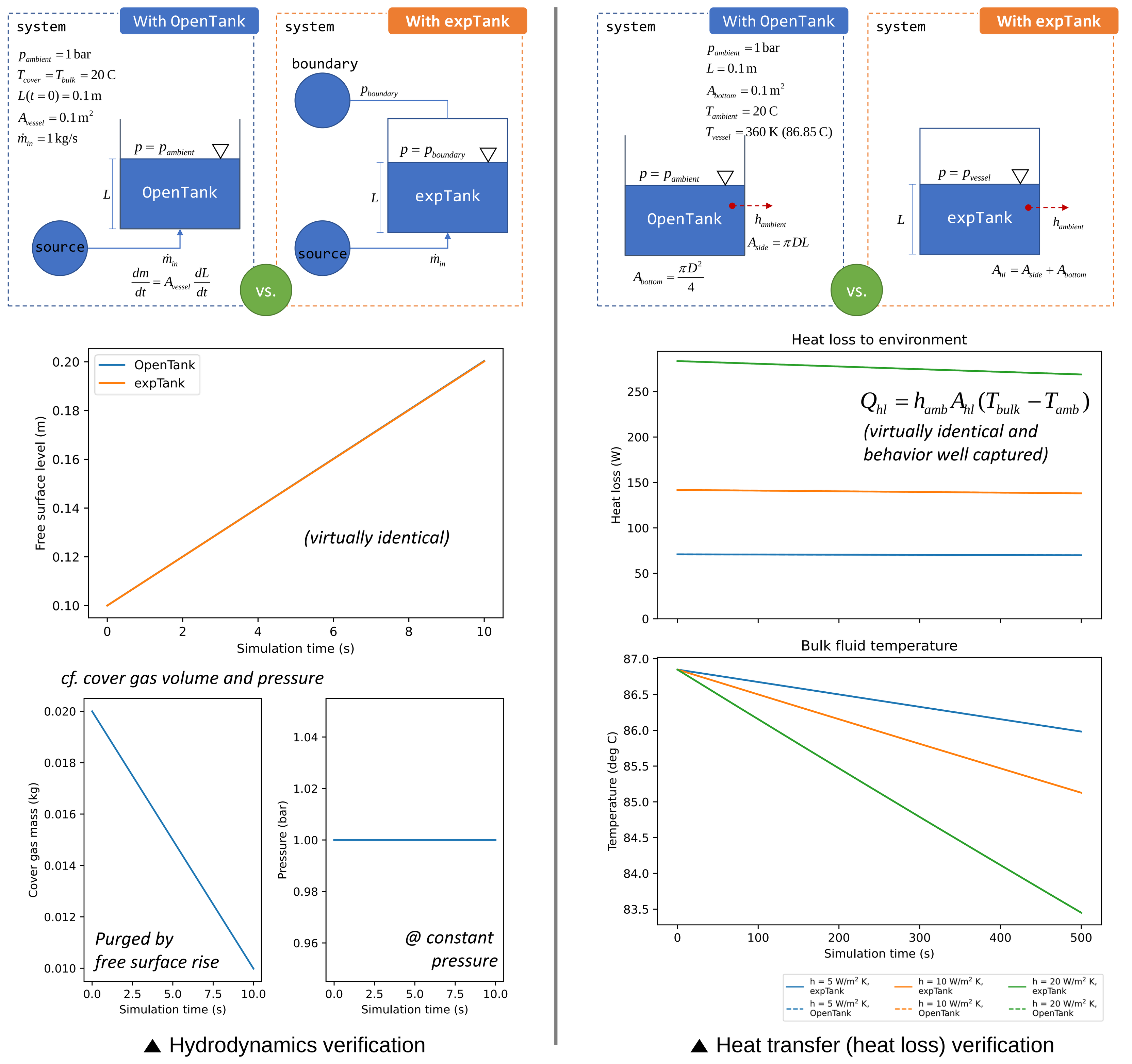
Model ExpansionTank

- Necessity of developing a separate model
  - Sodium free surface levels are anticipated to be affected by sodium net influx, sodium temperature change, and dynamic change of cover gas inventory
  - Cover gas and sodium should be treated separately so that the immiscible fluids can be tracked properly
  - No library model is able to capture this free surface dynamics
- Pointwise/one-dimensional formulations
  - No consideration on internal and local temperature and velocity distributions
  - High thermal conductivity of sodium suggests a rather uniform temperature distribution in space
  - Small temperature perturbations would be suppressed well due to the fact that large sodium flows only take place near the sodium inlets and outlets of the tanks



Numerical model verification

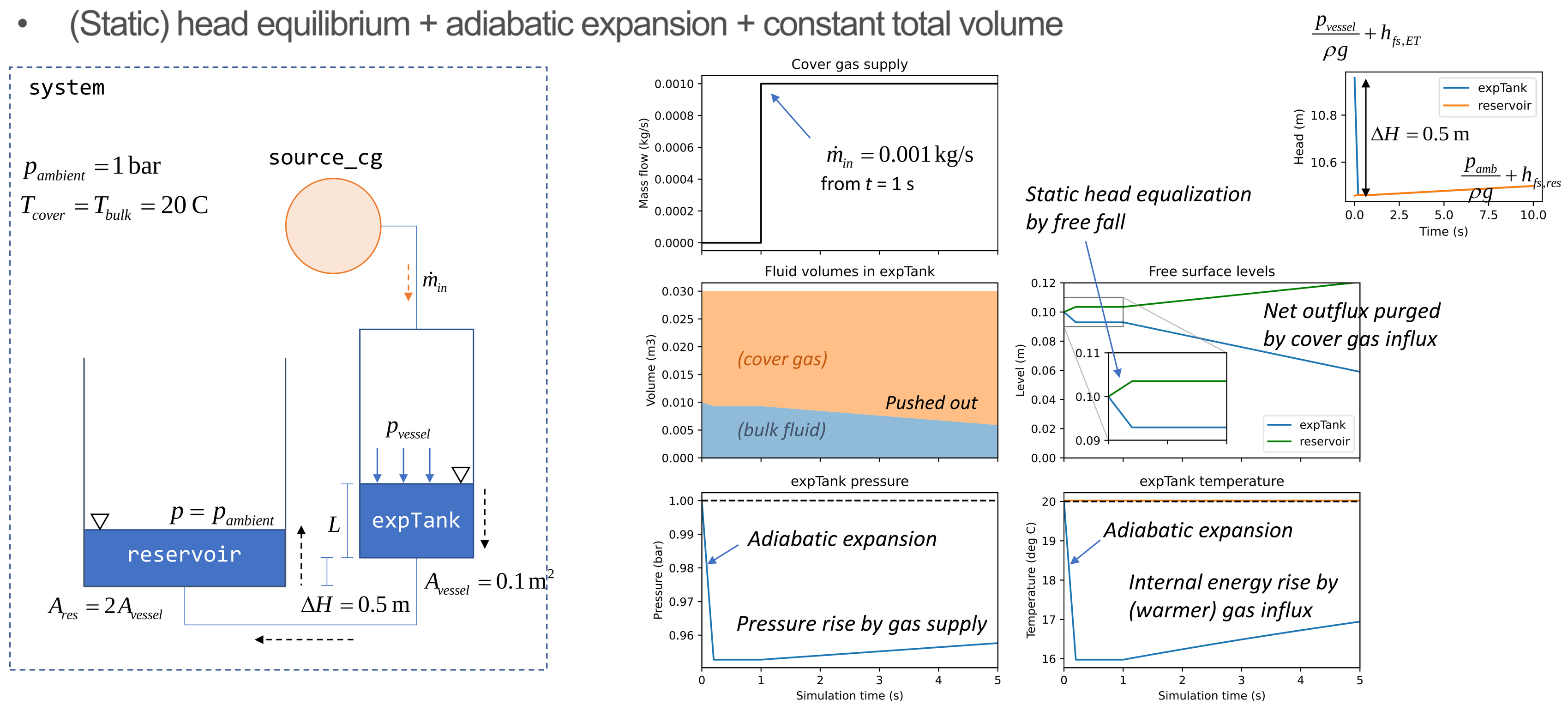
- Verified by code-to-code benchmarks to generic models from the Modelica base library
  - Mostly vs. `Modelica.Fluid.Vessels.OpenTank`
- Boundary conditions were set so that those compared were physically equivalent



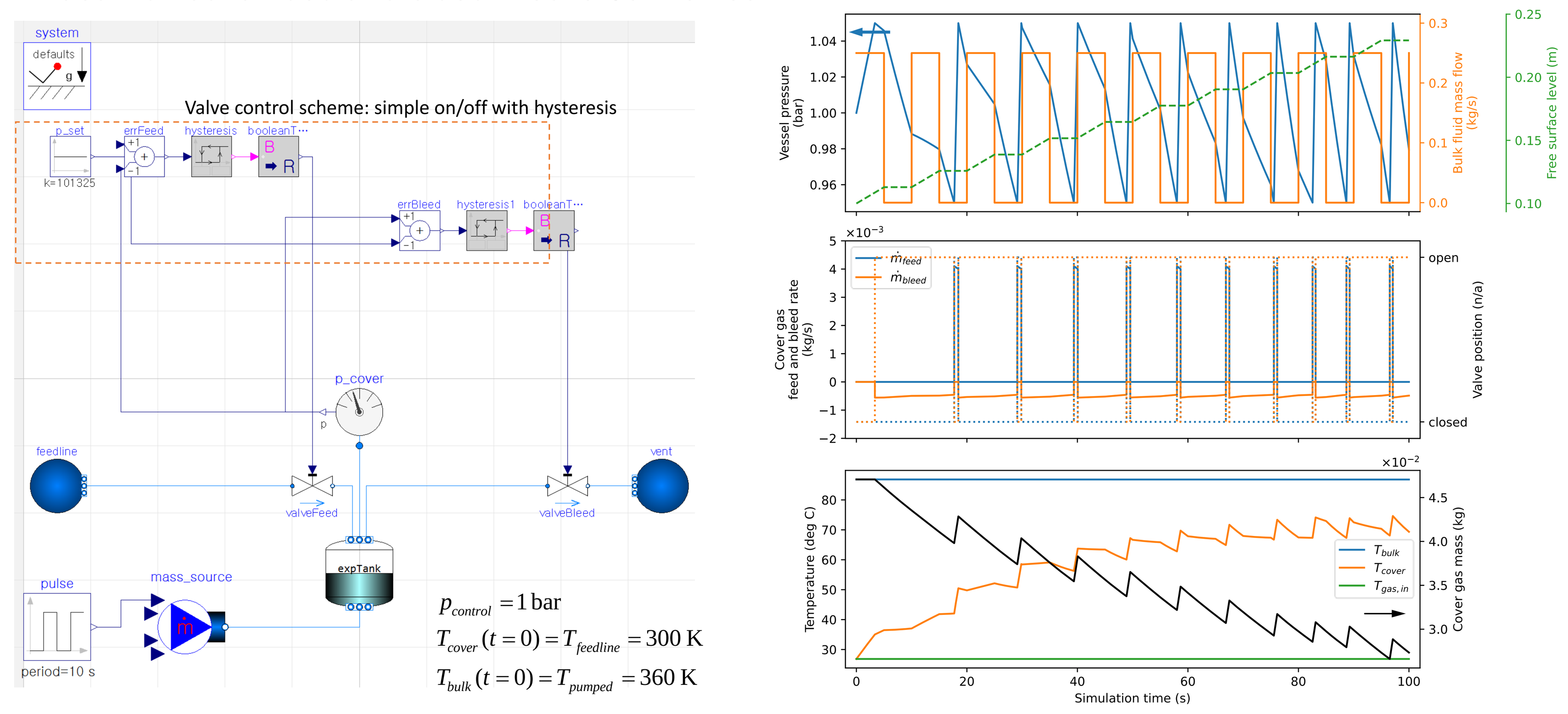
▲ Hydrodynamics verification ▲ Heat transfer (heat loss) verification

Preliminary simulations on the facility

- Working fluid transfer by cover gas purging: net cover gas influx
  - (Static) head equilibrium + adiabatic expansion + constant total volume



- Dynamic cover gas pressure control: automatic cover gas regulation
  - Feed-and-bleed system with hysteresis: no PID control; rather an on-off control
  - Ideal valves for feed and bleed lines: on/off valves



Summary

- Simulation capability on Modelica for the sodium TES verification test setup was established **to obtain its operational logics** and **to analyze the experimental results**
- **A dedicated model for the high- and low-temperature TES vessels is developed** to simulate the dynamic change of cover gas inventory
- Code-to-code benchmarks to similar models with valid boundary conditions were conducted; the physical behaviors are **correctly modeled** as defined
- We ran several preliminary case studies to analyze the behaviors of generic setups that can be directly thought to be similar to the test facility

Future work

- A nonlinear relation for the fluid volumes from the measured free surface level data will be set, as the vessels are **not cylindrical and finished with elliptic caps**
- Active volume control of cover gas will be implemented with **actual component logics**

ACKNOWLEDGMENTS

This work was supported by the National Research Foundation of Korea (NRF) (2021M2D1A1084836) and the National Research Council of Science & Technology (NST) (No. CAP20032-100) grant funded by the Korea government (Ministry of Science and ICT).

KAERI 한국원자력연구원 Korea Atomic Energy Research Institute