Numerical Investigation of Pipe Diameter Influence on Turbulent Behavior in Molten Salt Natural Circulation Systems

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Handong Global University · KNS Spring Meeting (Jeju, Korea) · May 7-8, 2026
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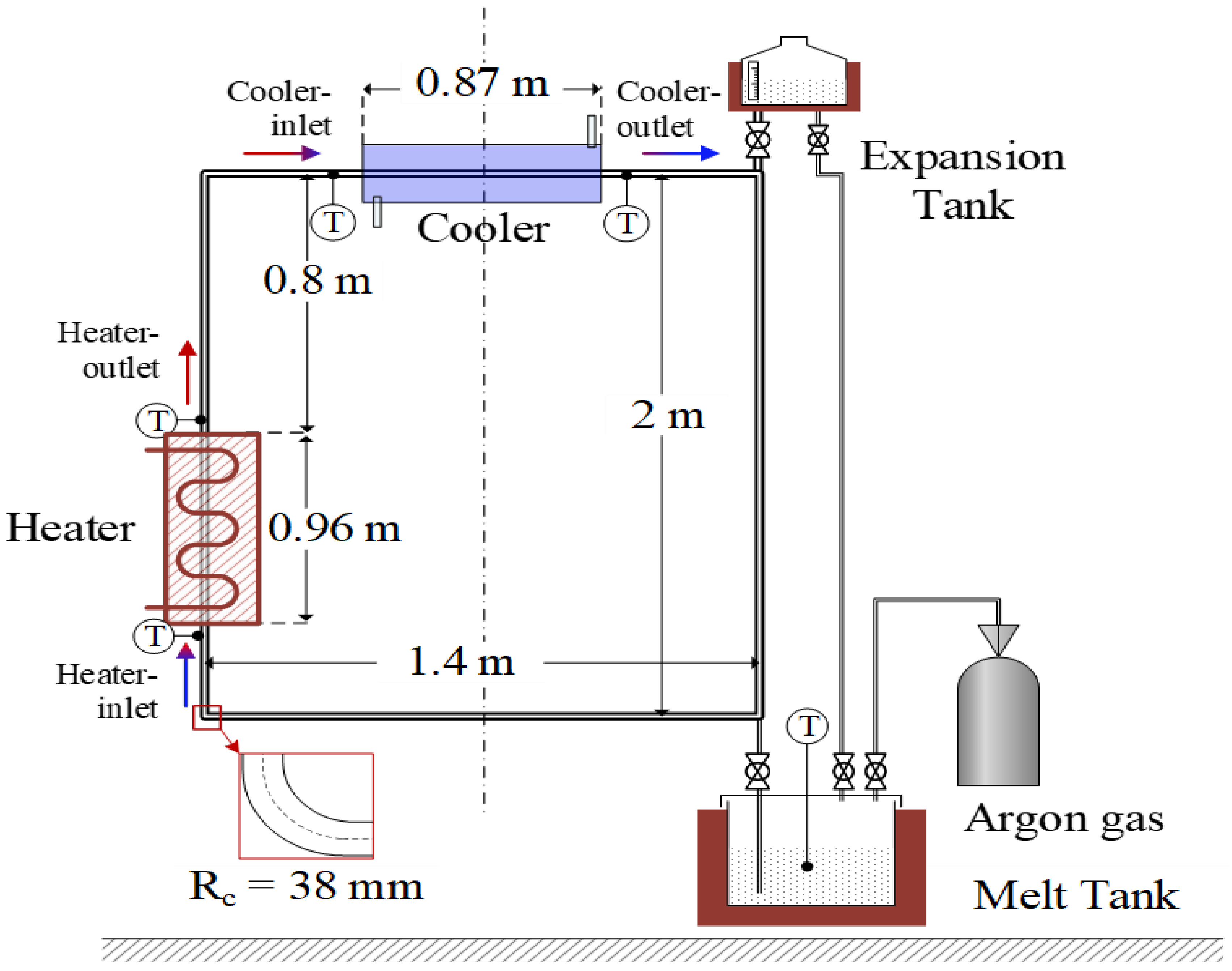
INTRODUCTION

This study investigates diameter-induced turbulence in molten salt NCLs using transient CFD simulations with the SST (URANS) model. Turbulence intensity is quantified through eddy viscosity ratio.

METHOD AND DESIGN

- A transient CFD model of the molten salt natural circulation loop was developed and validated against the MSNCL benchmark experiment, then extended to different pipe diameters to evaluate diameter-induced turbulence using the Transition-SST model.



- The transient flow and heat transfer behavior were solved using the conservation equations of mass, momentum, and energy, coupled with the Transition-SST model to capture laminar-to-turbulent transition.

- Eq. (1) describes the transport of turbulent kinetic energy, including transient, convective, production, dissipation, and diffusive terms.

$$\frac{\partial(\rho k_{TKE})}{\partial t}+\frac{\partial(\boldsymbol{u}_j)}{\partial x_j}=P_k-Y_k+\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k_{TKE}}{\partial x_j}\right] \qquad \text{Eq. (1)}$$

- Eq. (2) governs the transport of the specific dissipation rate, which controls the turbulence scale through corresponding production, dissipation, and diffusion mechanisms.

$$\frac{\partial(\rho\omega)}{\partial t}+\frac{\partial(\rho\boldsymbol{u}_j\omega)}{\partial x_j}=\alpha\frac{\omega}{k}P_k-\beta_t\rho\omega^2+\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\omega}\right)\frac{\partial\omega}{\partial x_j}\right] \qquad \text{Eq. (2)}$$

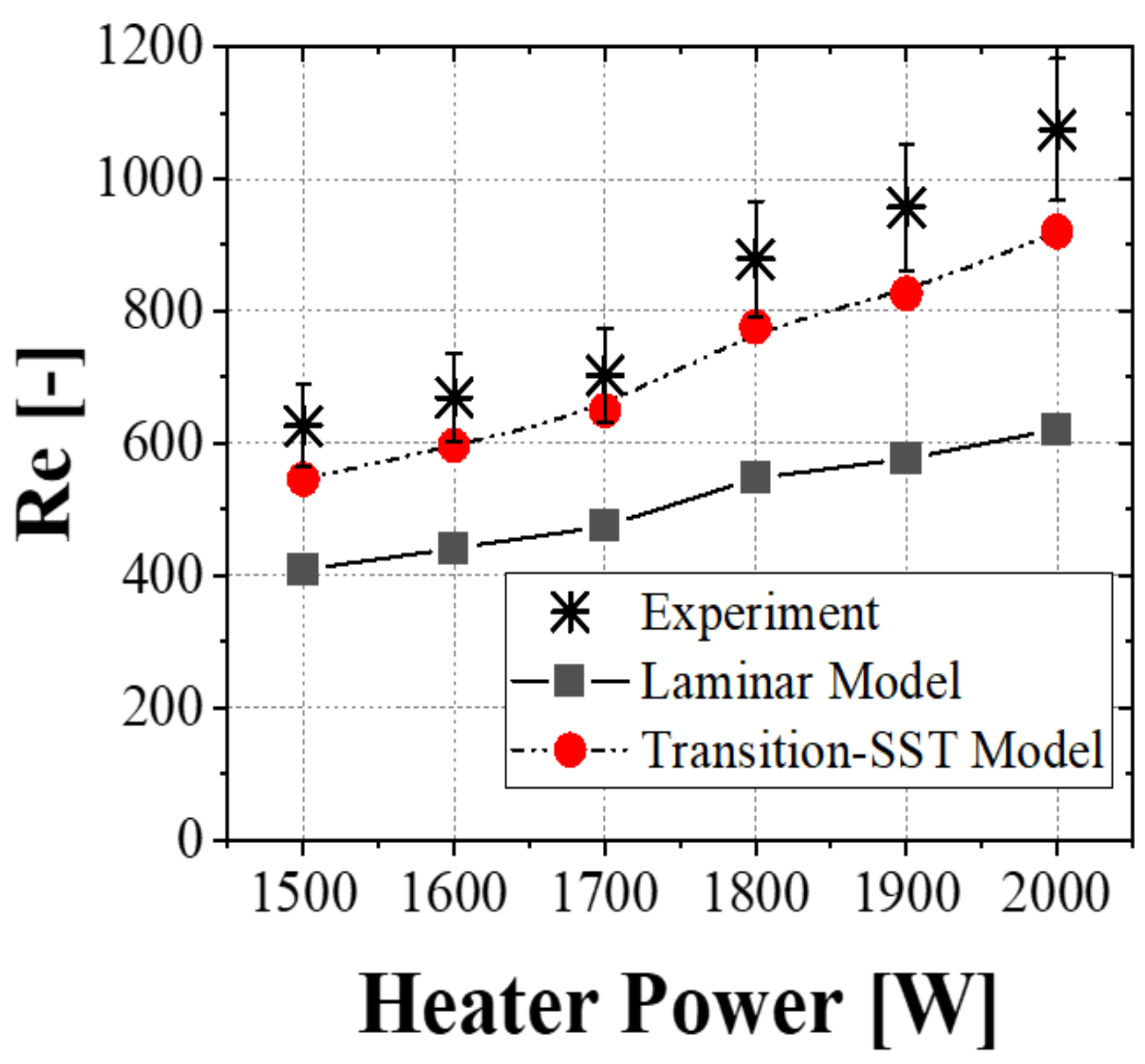
- Eq. (3) is the intermittency transport equation, enabling prediction of laminar-to-turbulent transition by modeling transition onset and suppression effects.

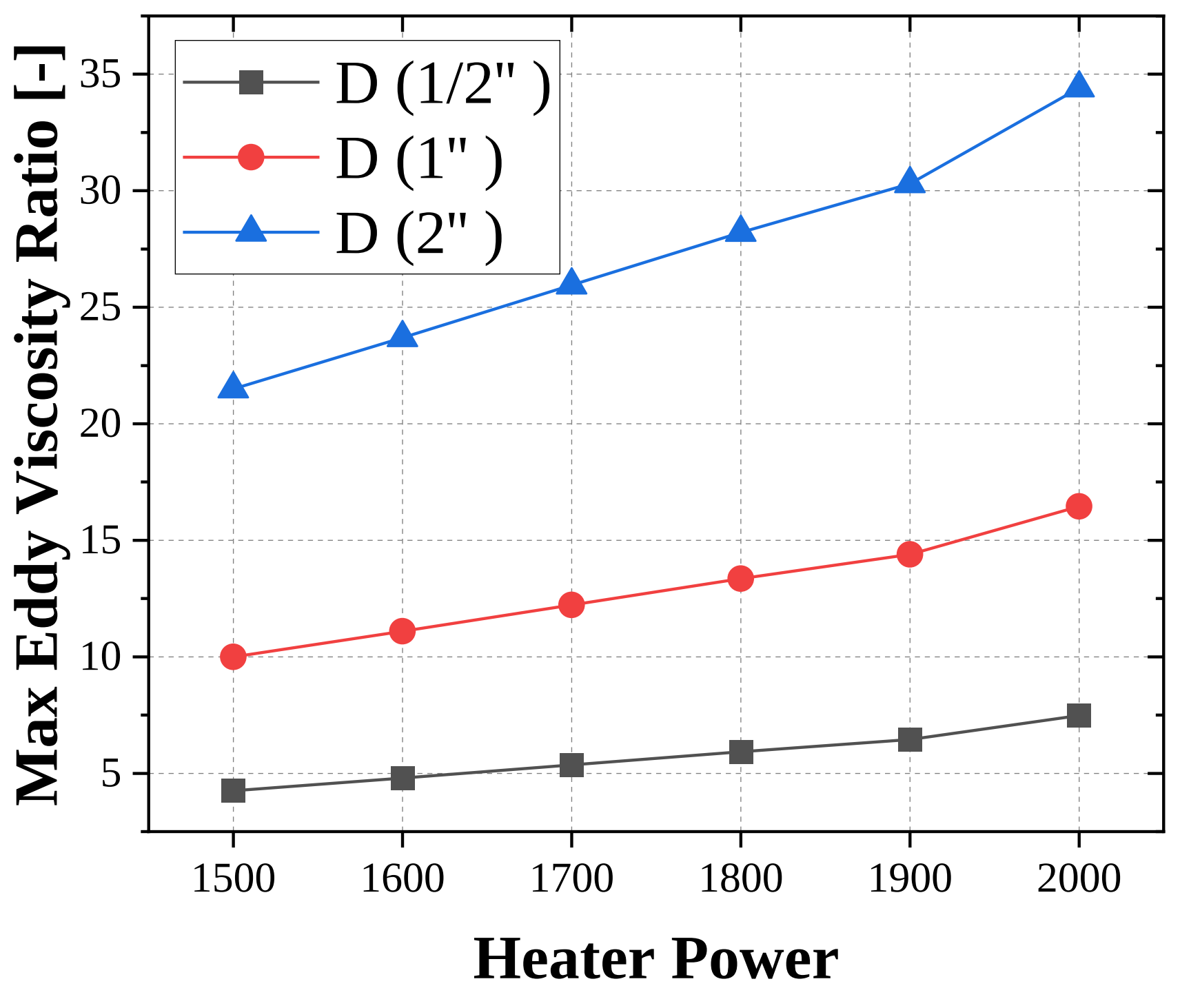
$$\frac{\partial(\rho\gamma)}{\partial t}+\frac{\partial(\rho\boldsymbol{u}_j\gamma)}{\partial x_j}=P_\gamma-E_\gamma+\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\gamma}\right)\frac{\partial\gamma}{\partial x_j}\right] \qquad \text{Eq. (3)}$$

RESULT

- The Transition-SST model showed better agreement with experimental Reynolds number data than the laminar model, confirming its suitability for capturing flow transition in molten salt natural circulation.

- The maximum eddy viscosity ratio increased with pipe diameter, indicating stronger localized turbulence even within the nominally laminar Reynolds number range.





CONCLUSION

In this study, an increase in pipe diameter in a molten salt natural circulation loop increases the maximum eddy viscosity ratio, and local turbulence can occur even when the overall Reynolds number remains within the laminar range.

This is due to velocity imbalances caused by strong radial temperature gradients near the heater wall; therefore, a transition-sensitive turbulence model such as Transition-SST is required for accurate predictions.

ACKNOWLEDGEMENT

This research was partially supported by the Regional Innovation System & Education (RISE) program through the Gyeongbuk RISE Center, funded by the Ministry of Education (MOE) and the Gyeongsangbuk-do/Pohang City, Republic of Korea. (2025-RISE-15-119). This work was also partially supported by Korea Hydro & Nuclear Power Co. and Local Government (Pohang). (2025).

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