# Convection Heat Transfer of NaK-78 Liquid Metal in a Circular Tube and a Tri-lobe Channel

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**Introduction:** Coolant type and shapes of coolant channels in solid-core nuclear reactors strongly affect pressure losses and the effectiveness of removing the fission heat generated in the reactor core. Circular channels, with the smallest surface area to volume ratio, are the least effective for cooling solid-core reactors. The tri-lobe coolant channels, with 28% larger surface and cross-section flow areas than a circular tube of the same equivalent hydraulic diameter, increase the surface area for heat transfer. Many experimental data and correlations are reported for turbulent convection of alkali liquid metals and alloys in circular tubes, however, to the best of the authors' knowledge, there are none available for tri-lobe channels (Figs. 1 and 2). Thus, this work performed 3-D Computational Fluid Dynamic (CFD) analyses to investigate the convective heat transfer of liquid NaK-78 (22wt% sodium, 78 wt% potassium) flows in a uniformly heated circular tube and in a tri-lobe channel of the same equivalent hydraulic diameter. The calculated wall temperatures and Nu values in the uniformly heated circular tube are compared to reported experimental measurements of Talanov and Ushakov (1967) (Fig. 1) at Peclet (Pe) number = 163 and 796. The CFD analyses results for the tri-lobe channel quantify the azimuthal variation of the local wall temperature, heat transfer Coefficient, and Nusselt number, Nu, and axial variation in the average Nusselt number, $\overline{Nu}$. The $\overline{Nu}$ values, for the tri-lobe channel are correlated and compared to the values for the circular tube (Fig. 1).

**Analyses Methodology:** The performed CFD analyses using the multi-physics commercial software, STAR-CCM+ Code version 9.04 examined the effect of using the two-layer realizable k-ε, the Shear Stress Transport (SST) k-ω, and the SST Detached Eddy Simulation (DES) turbulence models on the accuracy of the results and the computational time. The analyses for the circular tube and the tri-lobe channel, with an identical meshing grid configuration, used a uniform hexahedral core mesh and 12 exponentially refining prismatic layers near the wall to resolve the boundary layer (Fig. 2). The performed analyses are at the same inlet and exit temperatures and mass flux of the liquid NaK-78 flow, equivalent hydraulic diameter, the applied wall heat flux, and the setup in the experiments (Fig. 1). The k-ε and k-ω turbulent models employ a Prandtl number, $Pr_t$, which is the ratio of the eddy viscosity and eddy thermal diffusivity. To account for the high thermal diffusivity and the low momentum diffusivity of Nak-78 liquid metal, Reynolds' equation (Reynolds 1975), calculates higher $Pr_t$ (~1.5-2.2) than the default value in the STAR-CCM+ code (0.9).

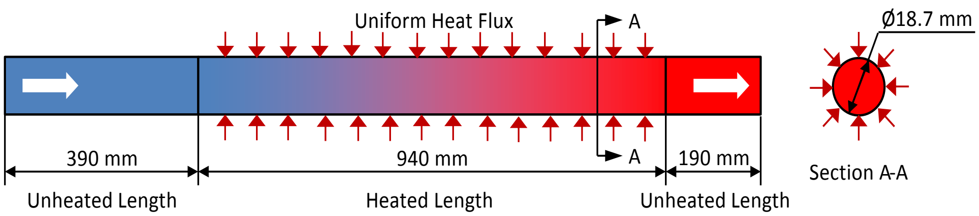


**Figure 1**: Cross-section views of test section in experiments (Talanov & Ushakov, 1967)

**Results:** The CFD analyses results for the uniformly heated circular tube are in good agreement with the reported experimental measurements (Talanov & Ushakov 1967). The calculated wall temperature and Nu using the DES and k-ω turbulence models are closer to the experimental measurements than those calculated using the k-ε model. Calculated wall temperatures along the heated length of the circular tube at Pe = 796 and 163, agree with experimental measurements, to within ± 0.4 K and ± 0.1 K, respectively. The calculated Nu values for fully developed flow of liquid NaK-78 at Pe = 796 are within ± 5% of the experimental values. For Pe = 163, although the experimental Nu values show large scattering, those calculated using the k-ω and DES models are within 9% of the mean, compared to 12% using the k-ε model. The calculated and measured Nu values for fully developed flows of NaK-78 in the experiments with uniformly heated circular tube (Fig. 1), are correlated as: $\mathbf{Nu = 5.6 + 0.013Pe^{0.863}}$. This correlation agrees to the reported experimental values to within ± 10%. The calculated Nu values using the k-ω and DES models agree with this correlation to within 2.1% and 2.6% at Pe = 163 and 796, respectively. Although the results using all three turbulence models are close to the experimental measurements, the computation time using the DES turbulence model is 13 and 14 times those using the k-ω and k-ε models, respectively. Unlike for the circular tube, the local wall temperature and Nu in the tri-lube channel varied azimuthally in a sinusoidal-like fashion (Fig. 3). The wall temperature is highest in the lobed corners, where flow is more restricted and the boundary layer is thicker. It is lowest along the concavities of the tri-lobe channel, where the boundary layer is thinner and the flow is less restricted (Fig. 2b). The values of $\overline{Nu}$ for NaK-78 fully developed flow in the tri-lobe channel, with a uniformly heated wall, are consistently higher that for the circular tube, of the same equivalent diameter and heated length (Fig. 4). The fully developed flow $\overline{Nu}$ values in the heated length of the tri-lobe channel is 7.4% and 8.8% higher than in the circular tube, at Pe = 796 and 163, respectively. The calculated values of $\overline{Nu}$ for fully developed flows in the uniformly heated tri-lobe channel are correlated, to within + 5%, as: $\overline{Nu} = 6.6 + 0.007\,Pe^{0.94}$. For Pe < 100, $\overline{Nu}$ values in the tri-lobe channel are ~15% higher than in the circular tube, with the difference gradually decreasing with increasing Pe.

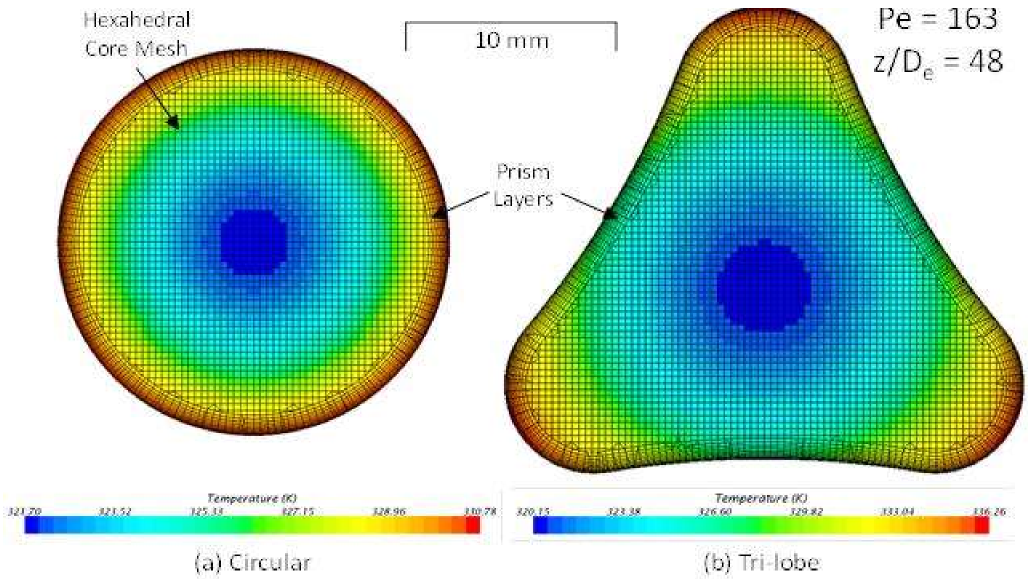


**Figure 2**: Mesh grid overlaid on calculated temperature fields using the k-ω turbulence model at Pe= 163 in: (a) the circular tube, and (b) the tri-lobe channel.

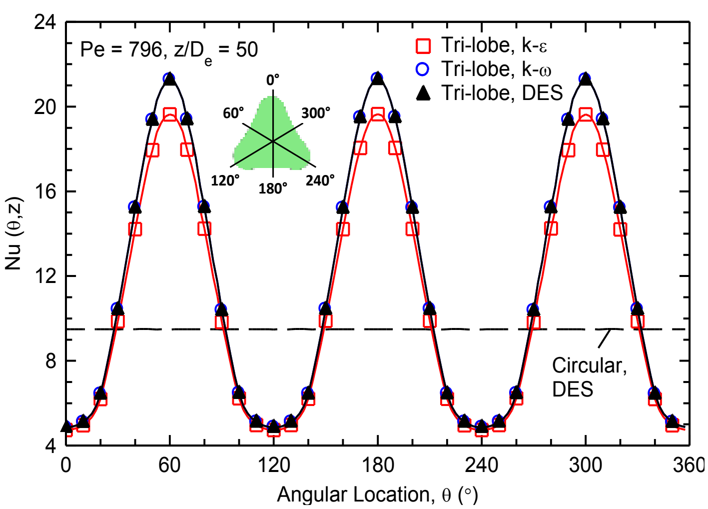


**Figure 3**: Calculated azimuthal variations of local Nu in tri-lobe channel, using three turbulence models, for Pe = 796.

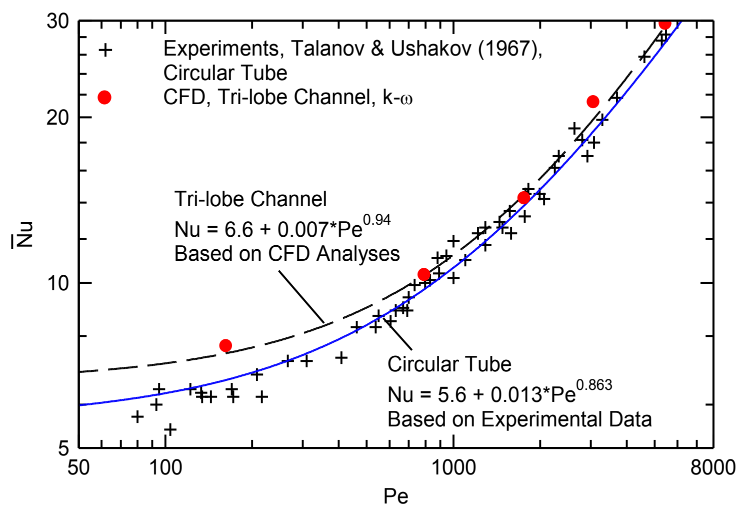


**Figure 4**: Developed Nusselt number correlations for NaK-78 fully developed flow in circular tube and tri-lobe channel.

## References:


Talanov, V.D. and Ushakov, P.A., 1967, *Study of Heat Transfer in Liquid Metals in Round Pipes*. In: Liquid Metals, P.L. Kirillov, V.I. Subbotin, and P.A. Ushakov Eds., Atomizdat, Moscow, 5-7.

Reynolds, A.J., 1975, "The prediction of turbulent Prandtl and Schmidt numbers", *Int. J. Heat and Mass Transfer,* **18**, 1055-1069.



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