§48. Computational Study of Forced Convection Heat Transfer for Heating of Liquid Metal in a Circular Tube

Hata, K. (Grad. School of Maritime Sciences, Kobe Univ.),
Masuzaki, S.

The knowledge of heat transfer from inner surface of a circular tube to forced flow of high temperature liquid metal in the laminar and transition regions is most important for design of cooling configurations such as plasma facing components in fusion reactor and ion beam targets with the flowing liquid metal.

The unsteady laminar three dimensional basic equations in boundary fitted coordinates as shown in Figs. 1 (A), (B) and (C) for a concentric annular tube with test tube inner diameter of 7.6 mm and outer diameter of 14.3 mm, and circular tubes with hydraulic diameter $d_H=(d_{out}-d)=6.7$ mm and with thermal equivalent diameter $d_{te}=(d_{out}^2-d^2)/d=19.3$ mm are numerically analyzed.

Figure 2 shows the typical z-axis variations in the measured local surface temperatures (T_s Δ), the corresponding local liquid bulk mean temperatures estimated by a linear interpolation of the measured inlet and outlet liquid temperatures (T_f ○) and the measured inlet and outlet liquid temperatures (T_{in}, T_{out} ●) for a concentric annular tube with test tube inner diameter of 7.6 mm and outer diameter of 14.3 mm, heated length of 52 mm and L/D of 6.84 at T_{in}=583.68 K and q=0.9971 MW/m^2 with u_{in}=0.0852 m/s. The numerical solutions for the local surface temperature, $T_{s,av}$, the analyzed temperature of the first control volume on the cylinder surface, *TEM*, and the corresponding local liquid bulk mean temperature, $T_{f,av}$, in the test section are shown as a blue solid line, a blue broken line and a blue 1-dot dashed line on the figure for comparison. The numerical solutions for the $T_{s,av}$ and the $T_{f,av}$ obtained from the theoretical equations for laminar heat transfer are in good agreement with the experimental values for the T_s (Δ) and the T_f (○). The increasing rate of the local surface temperature is approximately similar to that of the local liquid bulk mean temperature on the heated section. The corresponding local liquid bulk mean temperatures became also about 13.78 K lower parallel to the local surface temperatures by the each heated length. The rise temperature from the leading edge of the heated section to the outlet becomes $\Delta T_d=((T_{s,av})_{L=51.5mm}-T_{in})$=705.63 K-583.68 K=121.95 K. The numerical solutions for the $T_{s,av}$, the *TEM* and the $T_{f,av}$ for a circular tube with hydraulic diameter ($d_H=d_{out}-d$=6.7 mm) are shown as a red solid line, a red broken line and a red 1-dot dashed line in the figure for comparison. The corresponding local liquid bulk mean temperatures became also about 21.83 K lower parallel to the local surface temperatures by the each heated length. The rise temperature from the leading edge of the heated section to the outlet, $\Delta T_H=((T_{s,av})_{L=51.5mm}-T_{in})$=913.51 K-583.68 K=329.83 K, becomes about 2.70 times as large as the corresponding value for the concentric annular tube with test tube inner diameter of 7.6 mm and outer diameter of 14.3 mm, ΔT_d=121.95 K. The numerical solutions for the $T_{s,av}$, the *TEM* and the $T_{f,av}$ for a circular tube with thermal equivalent diameter ($d_{te}=(d_{out}^2-d^2)/d$ =19.3 mm) are shown as a green solid line, a green broken line and a green 1-dot dashed line in the figure for comparison. The corresponding local liquid bulk mean temperatures became also about 48.07 K lower parallel to the local surface temperatures by the each heated length. The rise temperature from the leading edge of the heated section to the outlet, $\Delta T_{te}=((T_{s,av})_{L=49.5mm}-T_{in})$=731.60 K-583.68 K=147.92 K, becomes about 1.21 times as large as the corresponding value for the concentric annular tube with test tube inner diameter of 7.6 mm and outer diameter of 14.3 mm, ΔT_d=121.95 K.

Figure 3 shows the numerical solutions for the steady state average Nusselt number on the surface of a heated section of 52 mm in length for the concentric annular tubes with d_H=6.7 mm (a) and d_{te}=19.3 mm (b) and, for the circular tubes with d_H=6.7 mm (c) and d_{te}=19.3 mm (d) at q=0.9771 MW/m^2. The relation between the $Nu_{av,d}$ and the Pe for a concentric annular tube with d_H=6.7 mm (a△) is almost in good agreement with that for the experimental data and the numerical solutions (○) previously obtained [1]. The values of the $Nu_{av,Ate}$ and Pe for a concentric annular tube with d_{te}=19.3 mm (b□) are 2.88 times larger than those for a concentric annular tube with d_H=6.7 mm (a△). The $Nu_{av,H}$ for a circular with d_H=6.7 mm (c△) become 32.14 % lower than that for a concentric annular tube with d_H=6.7 mm (a△). The $Nu_{av,te}$ for a circular tube with d_{te}=19.3 mm (d□) becomes 71.14 % lower than that for a concentric annular tube with d_{te}=19.3 mm (b□) at Pe=25.07, although that is 16.84 % lower than that for a concentric annular tube with d_H=6.7 mm (a△).

The analysis result for a circular tube with the thermal equivalent diameter has considerably showed a similar tendency with an analysis result of a concentric annular tube more but it is judged that the analysis results of the concentric annular and circular tube with the hydraulic diameter are more rational in the relations between the average Nusselt number, Nu_{av}, and the Peclet number, Pe than those with the thermal equivalent diameter. The numerical analyses for the concentric annular and circular tube with the hydraulic diameter are usually performed according to conventional rearranging technique and the general correlations for the laminar and transition forced convection heat transfer of high temperature liquid metal are derived for wide ranges of test tube inner diameters, d_H, heat fluxes, q, and inlet flow velocities, u_{in}.

1) Shiotsu, M. et al.: NURETH-6, Vol. 2 (1993) 1292-1301.

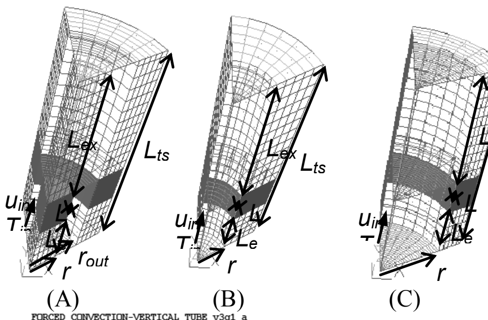

Fig. 1 Boundary fitted coordinates: a concentric annular tube with d=7.6 mm and d_{out}=14.3 mm (A) and, circular tubes with d_H=6.7 mm (B) and d_{te}=19.3 mm (C).

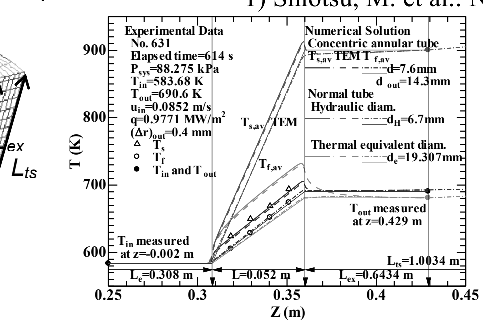

Fig. 2 $T_{s,av}$ and $T_{f,av}$ for a concentric annular tube with d=7.6 mm (A) and circular tubes with d_H=6.7 mm (B) and d_{te}=19.3 mm (C) compared with experimental data for a concentric annular tube.

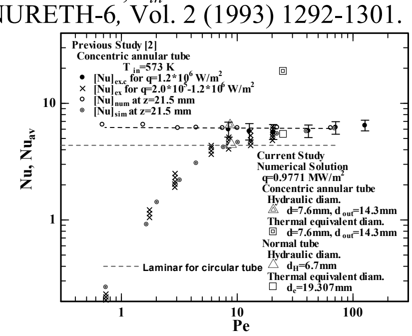

Fig. 3 Nu_{av} for a concentric annular tube with d_H=6.7 mm (a) and d_{te}=19.3 mm (b) and, circular tubes with d_H=6.7 mm (c) and d_{te}=19.3 mm (d) versus Pe.