

# APPLICABILITY OF HEAT TRANSFER COEFFICIENT CORRELATIONS TO SINGLE-PHASE CONVECTION IN LIQUID METALS

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Different correlations for convective heat transfer under fully developed single-phase turbulent flow have been compared. The purpose of this comparison is to evaluate their applicability to a liquid-metal system employing the eutectic NaK at 900 K flowing inside an annulus with a hydraulic diameter of 1.823 cm. The NaK liquid velocities range between 0.25 and 3 m/s. The corresponding Reynolds numbers (Re) for these velocities vary between 21,000 and 254,000, values of fully developed turbulent flow. The Prandtl number (Pr) for NaK at 900 K is 0.0053, typical of a liquid metal.

The correlations compared follow:

Lubarsky and Kaufman (Refs. 1 and 2),

$$\text{Nu} = 0.625\text{Pe}^{0.4}. \quad [ 1 ]$$

Seban and Shimazaki (Ref. 3), also developed by Subbotin et al. (Ref. 4),

$$\text{Nu} = 5 + 0.025\text{Pe}^{0.8}. \quad [ 2 ]$$

Lyon (Ref. 5), a correlation for uniform heat-flux conditions,

$$\text{Nu} = 7 + 0.025\text{Pe}^{0.8}, \quad [ 3 ]$$

which is very similar to the previous Eq. [2] but with the constant term 7 instead of 5.

Reed, for uniform wall temperature conditions (Eq. 8.2 of Ref. 6),

$$\text{Nu} = 3.3 + 0.02 \text{Pe}^{0.8}. \quad [ 4 ]$$

Kottowiski (Ref. 7), which applies to flows in annuli with radii  $r_2$  and  $r_1$ ,

$$\text{Nu} = 0.75(r_2/r_1)^{0.3}(7 + 0.025\text{Pe}^{0.8}). \quad [ 5 ]$$

All of these correlations were developed for liquid metals, and they are functions of the Peclet number (Pe). In addition, the well known and widely used Dittus-Boelter (Ref. 8) correlation,

$$\text{Nu} = 0.023\text{Re}^{0.8}\text{Pr}^{0.4}, \quad [ 6 ]$$

was also considered in this comparison. The Dittus-Boelter correlation applies to liquids and gases with  $\text{Pr} > 0.7$ , like water. This correlation is a function of both the Re and the Pr numbers and has two different versions depending on cooling or heating conditions (the exponent of Pr is 0.4 for heating and 0.3 for cooling, and the coefficient at the front is 0.023 for heating and 0.026 for cooling). Ref. 6 describes all of these correlations in Chaps. 4 and 8.

Fig. 1 shows the calculated Nusselt numbers (Nu) using the different correlations for NaK as a function of the coolant velocity. The results of the Dittus-Boelter correlation, either for heating or cooling, are well above the values calculated by the other correlations that apply to liquid metals. Fig. 2 shows the calculated Nu for the correlations that apply only to liquid metals; they all compare reasonably well. Out of these, the Lyon (for uniform heat flux) and the Seban-Shimazaki correlations yield the highest values, and the Reed correlation (for uniform temperature) yields the lowest values. The Lubarsky-Kaufman and the Kottowiski correlations are in very good agreement. The Reed correlation is the most conservative one yielding the lowest calculated Nu values. These figures show the importance of employing the appropriate correlation for the fluid of interest. The Dittus-Boelter correlation obviously does not apply to liquid metals.

The Lubarsky-Kaufman correlation has been selected as the correlation to be used for fully developed turbulent convective heat transfer in liquid metals. This is the same correlation recommended by Peterson (Ref. 9) as well. A version of the RELAP5/ATHENA computer code (Ref. 10) has been developed at Oak Ridge National Laboratory, with the appropriate correlations for liquid metals implemented into the different fluid flow regimes. The Lubarsky-Kaufman correlation has been implemented in the code for single-phase turbulent forced convection. Results obtained with this computer code have been published before (Ref. 11) as part of the design of a space reactor employing lithium and potassium in a Rankine system. Comparison of RELAP5/ATHENA results to one of the Peterson experiments (Ref. 12) is presented here.

The simulated experiment was performed in a facility with a vertical tube, made of Haynes-25 alloy (a cobalt-nickel-tungsten superalloy), 1.7-cm (0.67-in.) inside diameter, 1.905-cm (0.75-in.) outside diameter, and 232.41 cm (91.5 in.) long. The tube is inside a shell, 5.26-cm (2.07-in.) inside diameter. In the simulated experiment, hot

liquid sodium circulated in down-flow between the tube and the shell, entering the top at 1234 K and leaving the bottom of the shell at 1213 K. Potassium circulated in up flow (counter-current to the sodium) inside the tube. Liquid potassium entered the bottom of the tube at 1045 K and left the top of the tube as vapor at 1140 K, with a superheat of ~70 K. The pressures at the inlet and outlet of the potassium side were 291.9 and 139.61 kPa. The mass flow rate of potassium was 0.038 kg/s.

The RELAP5/ATHENA model of the vertical tube and shell employed 198 vertical nodes, each 1.1738 cm long. Material properties for Haynes-25 were input into the code. Comparison of experimental data and the ATHENA-calculated results for both the sodium and the potassium sides, are given in Fig. 3. The experimental and the calculated temperatures during single-phase liquid-forced convection, either in the sodium or in the potassium side, agree very well. These results confirm the applicability of the Lubarski-Kaufman correlation to single-phase liquid-forced convection conditions.

In conclusion, this comparison shows the importance of using the appropriate heat transfer correlations for the fluid considered. Both properties of the fluid and the appropriate heat transfer correlations are needed in thermal-hydraulic computer codes that will be used with different fluids.

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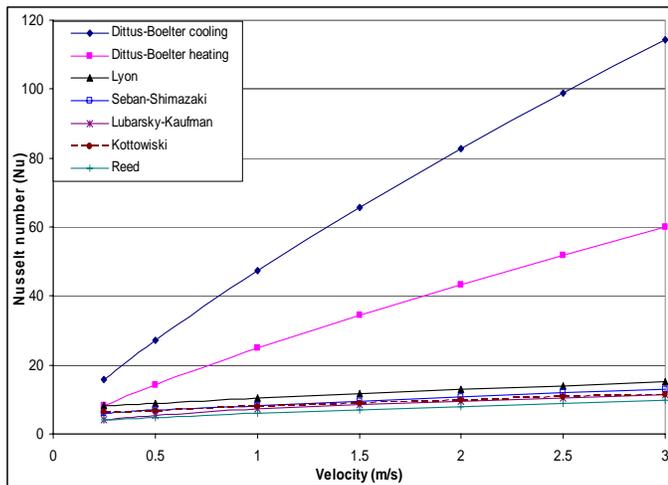


Fig. 1. Comparison of the different heat transfer correlations.

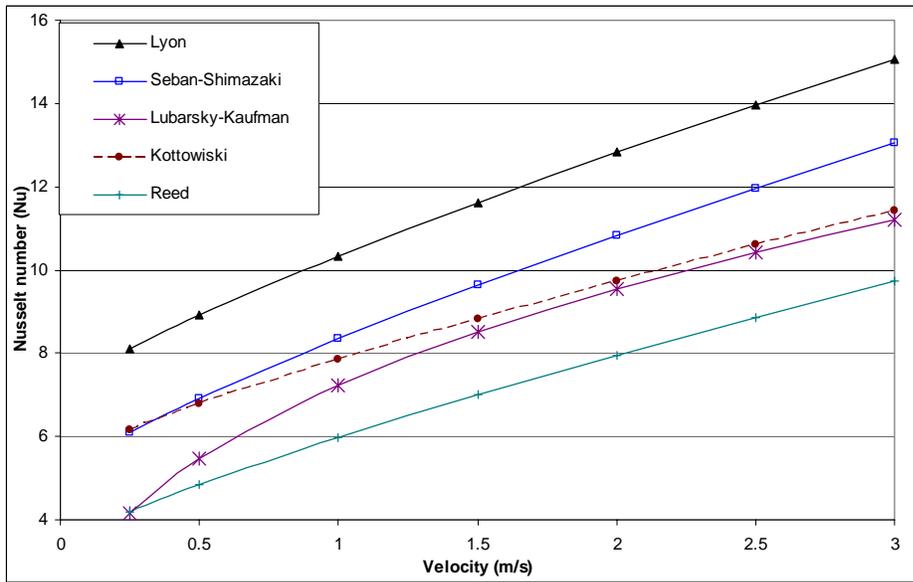


Fig. 2. Comparison of heat transfer correlations for liquid metals.

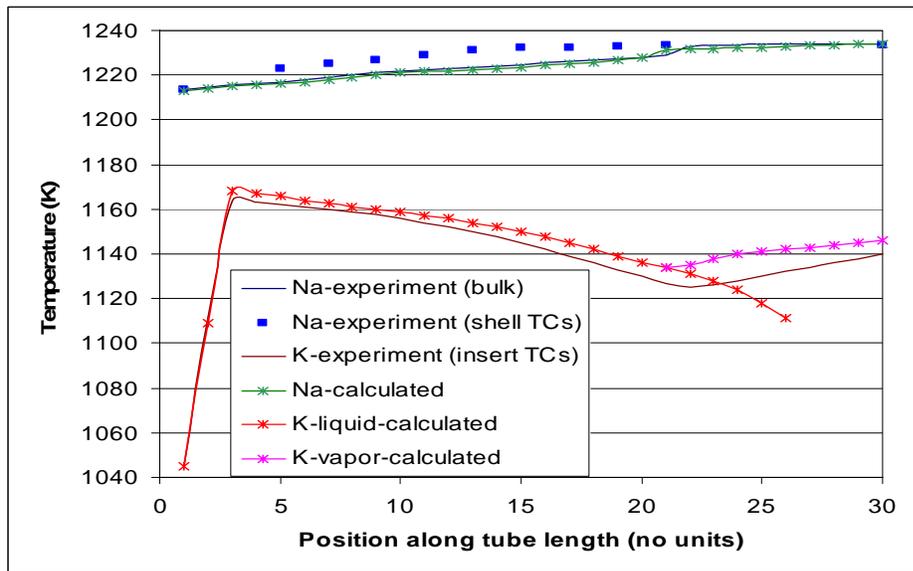


Fig. 3. Experimental and calculated temperatures for Peterson experiment (Ref. 12).