Analysis of Heat Transfer Correlations for Sodium Flows in an IHX of a SFR

Seok-Ki Choi and Seong-O Kim
Fast Reactor Development Division, Korea Atomic Energy Research Institute, 150-1 Deokjin-dong, Yuseong, Daejeon, Korea, skchoi@kaeri.re.kr

1. Introduction

The design of the intermediate heat exchanger (IHX) in a sodium cooled fast reactor needs the heat transfer correlations for a parallel flow, a cross flow and an inclined flow. However, the experimental correlations for liquid metal such as sodium are rare since the experiment is very expensive and difficult. This fact leads us to perform CFD calculations to evaluate the previous correlations. The CFD at present is mature enough to calculate complex flows and the CFD calculation of a sodium heat transfer does not need a special treatment. In the present study the existing sodium heat transfer correlations for the design of an IHX are evaluated by the CFD results and the compared results are presented.

2. Liquid Metal Heat Transfer Correlations

2.1 Parallel Flow

The liquid metal heat transfer correlations for a parallel flow are relatively abundant compared with those for cross flow and inclined flows.

(1) Graber-Rieger correlation :

$$Nu = 0.25 + 6.20(\frac{P}{D}) - 0.007 + 0.032(\frac{P}{D})(Pe)^{0.8-0.024(\frac{P}{D})} \quad (1)$$

(2) Lubarsky-Kaufman correlation:

$$Nu = 0.625(Pe)^{0.4} \quad (2)$$

(3) Seban-Shimazaki correlation:

$$Nu = 5.0 + 0.025(Pe)^{0.8} \quad (3)$$

(4) Kisohara et al. correlation:

$$Nu = 4.77 + 0.728(Pe)^{0.454} \quad (4)$$

(5) Tang et al. correlation (2DHX):

$$Nu = 4.0 + 0.33(P/D)^{3.8}(Pe/100)^{0.86} + 0.16(P/D)^{5.0} \quad (5)$$

(6) Present correlation:

$$Nu = 0.16 + 4.03(\frac{P}{D}) - 0.005 + 0.021(\frac{P}{D})(Pe)^{0.8-0.024(\frac{P}{D})} \quad (6)$$

2.2 Cross Flow

Three liquid metal heat transfer correlations for a cross flow are considered;

(1) Hsu Correlation:

$$Nu = 0.958\left(\frac{\phi_1}{D}\right)^{0.5}\left(\frac{P-D}{P}\right)^{0.5}(Pe_{v,\max})^{0.5} \quad (7)$$

(2) Kalish and Dwyer Correlation:

$$Nu = \left(\frac{\phi_1}{D}\right)^{0.5}\left(\frac{P-D}{P}\right)^{0.5}\left(6.19 + 0.2665\,[Pe_{v,\max}]^{0.635}\right) \quad (8)$$

(3) Dwyer Correlation (2DHX):

$$Nu = \left(\frac{\phi_1}{D}\right)^{0.5}\left(\frac{P-D}{P}\right)^{0.5}\left(5.36 + 0.1974\,[Pe_{v,\max}]^{0.682}\right) \quad (9)$$

2.3 Inclined Flow

Three liquid metal heat transfer correlations for inclined flows exist and they are;

(1) Kalish and Dwyer Correlation:

$$Nu = \left(\frac{\phi_1}{D}\right)^{0.5}\left(\frac{P-D}{P}\right)^{0.5}\left[\frac{\sin\beta + \sin^2\beta}{1+\sin^2\beta}\right]^{0.5}\left(5.44 + 0.228\,[Pe_{v,\max}]^{0.614}\right) \quad (10)$$

(2) Dwyer Correlation:

$$Nu = 0.958\left(\frac{\phi_1}{D}\right)^{0.5}\left(\frac{P-D}{P}\right)^{0.5}\left[\frac{\sin\beta + \sin^2\beta}{1+\sin^2\beta}\right]^{0.5}[Pe_{v,\max}]^{0.5} \quad (11)$$

(3) 2DHX Correlation:

$$Nu = \left(\frac{\phi_1}{D}\right)^{0.5}\left(\frac{P-D}{P}\right)^{0.5}\left[\frac{\sin\beta + \sin^2\beta}{1+\sin^2\beta}\right]^{0.5}\left(5.36 + 0.1974\,[Pe_{v,\max}]^{0.682}\right) \quad (12)$$

3. Results and Discussions

Calculations are performed for a parallel flow, a cross flow ($\beta = 90$) and two different inclined flows ($\beta = 60,30$). The CFX-11 commercial code is employed for the calculations and four turbulence models such as

SST, RNG-$k-\varepsilon$, SSG-RSTM and Omega-RSTM are tested for present purpose. The results by the SST and SSG-RSTM turbulence models are presented here because these two models outperform the other two models.

Fig.1 shows the predicted average Nusselt number for a parallel flow together with the correlations mentioned above. It is shown that the correlation by Graber-Rieger over-predicts the heat transfer coefficient, and it is also observed that the correlations by Lubarsky-Kaufman and by Seban-Shimazaki under-predict the average Nusselt number. The new correlation (Eq.(6)) is proposed to match well with the numerical solution.

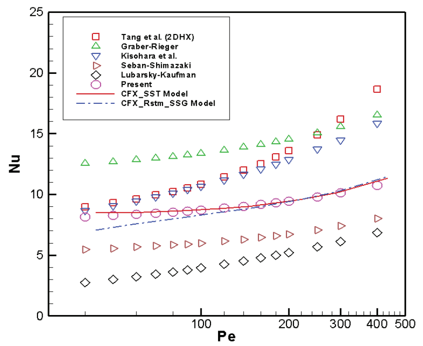

Fig.1 Nusselt number vs Peclet number for parallel flow

Fig.2 shows the variation of the average Nusselt number according to the Peclet number for cross flow. It is observed that the present numerical solution by SST turbulence model follows the trend of Dwyer correlation, while the SSG-RSTM model matches well with the Hsu's correlation. Since Hsu's correlation does not work well in the low Peclet number region, the use of Dwyer's correlation (Eq.(9)) is recommended as in the 2DHX code.

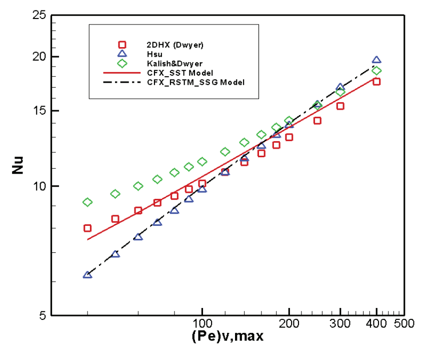

Fig.2 Nusselt number vs Peclet number for cross flow ($\beta = 90$)

Figs 3-4 show that the present numerical solution follows the Dwyer correlation for flows with 60 and 30 degree inclination. Except for the very low Peclet number region the correlation by Kalish and Dwyer under-predicts severely the average Nusselt number, especially when the inclined angle is grave ($\beta = 30$). Thus, the use of the Dwyer correlation (Eq.(12)) for inclined flows is promising.

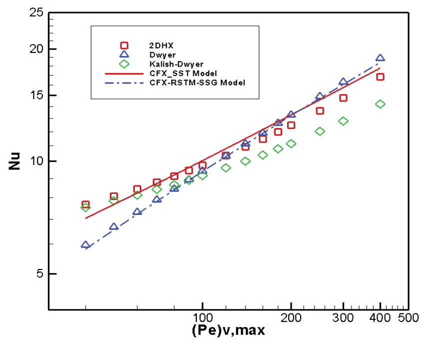

Fig.3 Nusselt number vs Peclet number for inclined flow ($\beta = 60$)

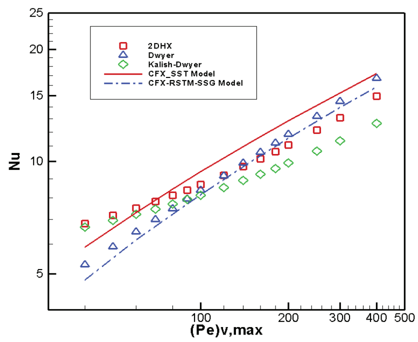

Fig.4 Nusselt number vs Peclet number for inclined flow ($\beta = 30$)

5. Conclusions

A numerical study has been performed to find a better correlation for the design of an IHX in a sodium cooled fast reactor. Three different flow situations, such as a parallel flow, a cross flow and an inclined flow, are considered. For a parallel flow, the old correlations do not match with the present numerical results. Thus a new correlation is proposed. For a cross flow, the Dwyer's correlation (Eq.(9)) works best. For inclined flows, the modified Dwyer's solution (Eq.(12)) matches well with the present numerical results. It is observed that the present calculation shows that the original Dwyer correlation works better than the modified Kalish-Dwyer correlation (Eq.(10)).

REFERENCES

[1] Y. S. Sim, Evaluation of Pressure Loss and Heat Transfer Correlations for Inclined Flow in ASTEEPL and 2DHX Codes, KALIMER/FS200-AR-O/1999.

[2] N. Kisohara et al, Development of a Double-Wall-Tube Steam Generator - Evaluation of Thermal Hydraulic Tests on High Mass Flow Rate Condition, JNC TN9400, 2001.