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Numerical Validation of Heat Transfer Correlations for Design of the Intermediate Heat Exchanger in a Sodium Cooled Fast Reactor

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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 flow. Among them, the following three correlations are considered in the present study;

(1) Graber-Rieger correlation :

$$Nu = a + b(Pe)^c \quad (1)$$

$$a = 0.25 + 6.20(P/D) \quad (2)$$

$$b = -0.007 + 0.032(P/D) \quad (3)$$

$$c = 0.8 - 0.024(P/D) \quad (4)$$

(2) Lubarsky-Kaufman correlation:

$$Nu = 0.625(Pe)^{0.4} \quad (5)$$

(3) Seban-Shimazaki correlation:

$$Nu = 5.0 + 0.025(Pe)^{0.8} \quad (6)$$

(4) JAEA correlation:

$$Nu = 4.77 + 0.728(Pe)^{0.454} \quad (7)$$

2.2 Cross Flow

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

(1) Hsu Correlation:

$$Nu = 0.958\left(\frac{\phi_1}{D}\right)^{0.5}\left(\frac{P-D}{P}\right)^{0.5}(Pe_{v,\max})^{0.5} \quad (8)$$

(2) Kalish and Dwyer Correlation:

$$Nu = \left(\frac{\phi_1}{D}\right)^{0.5}\left(\frac{P-D}{P}\right)^{0.5}\left(6.19 + 0.2665\,[Pe_{v,\max}]^{0.635}\right) \quad (9)$$

(3) Dwyer Correlation:

$$Nu = \left(\frac{\phi_1}{D}\right)^{0.5}\left(\frac{P-D}{P}\right)^{0.5}\left(5.36 + 0.1974\,[Pe_{v,\max}]^{0.682}\right) \quad (10)$$

2.3 Inclined Flow

Only two liquid metal heat transfer correlations for an inclined flow exist within the present author's knowledge and they are;

(1) Kalish and Dwyer Correlation:

$$Nu = \left(\frac{\phi_1}{D}\right)^{0.5}\left(\frac{P-D}{P}\right)^{0.5}\left[\frac{\sin\beta + \sin^2\beta}{1+\sin^2\beta}\right]^{0.5}\left(5.44 + 0.228\,[Pe_{v,\max}]^{0.614}\right) \quad (11)$$

(2) Dwyer Correlation:

$$Nu = 0.958\left(\frac{\phi_1}{D}\right)^{0.5}\left(\frac{P-D}{P}\right)^{0.5}\left[\frac{\sin\beta + \sin^2\beta}{1+\sin^2\beta}\right]^{0.5}[Pe_{v,\max}]^{0.5} \quad (12)$$

3. Results and Discussions

Calculations are performed for a parallel flow, a cross flow ($\beta = 90$) and four different inclined flows ($\beta = 75, 60, 45, 30$). The CFX-11 commercial code is employed for the calculations and the Shear Stress Transport (SST) turbulence model is used. Typically the 500,000 numerical grids are generated for the calculations. The numerical grids for the calculation of a cross flow are shown in Fig.1.

Fig.2 shows the predicted average Nusselt number for a parallel flow together with the correlations mentioned above. It is shown that the present numerical results agree well with the correlation by Graber-Rieger, and it is also observed that the correlations by Lubarsky-Kaufman and by Seban-Shimazaki under-predict the average Nusselt number.

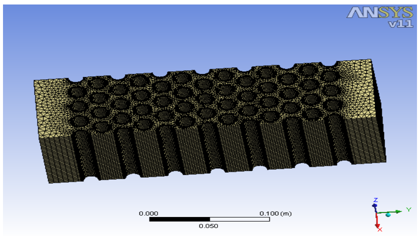

Fig.1 Numerical grids for cross flow

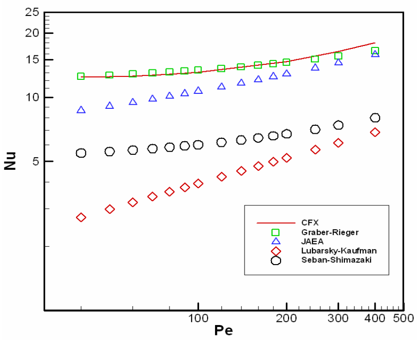

Fig.2 Nusselt number vs Peclet number for parallel flow

Fig.3 shows the variation of average Nusselt number according to Peclet number. It is observed that when the Peclet number is small, the present numerical solution follows the trend of Dwyer correlation, while when the Peclet number becomes larger, it follows the correlation by Kalish and Dwyer. In general the present solution follows the average of three correlations. Except for the low Peclet number region, the general behaviors of the three correlations are similar although the Dwyer correlation slightly under-predicts the average Nusselt number.

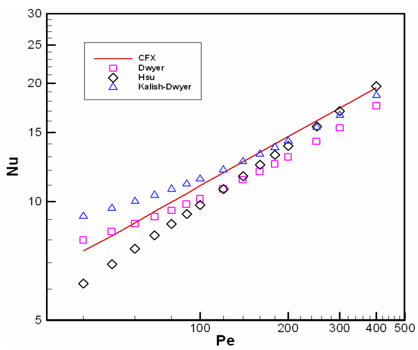

Fig.3 Nusselt number vs Peclet number for cross flow ($\beta = 90$)

Figs 4-5 show that the present numerical solution follows the Dwyer correlation for flows with 60 and 30 degree inclination. Except for 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 for inclined flows is promising.

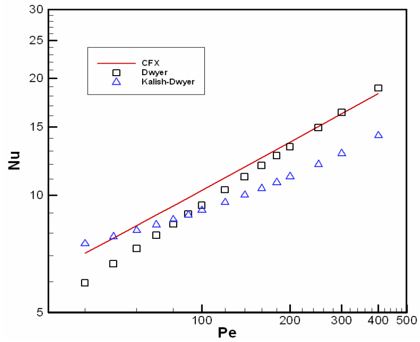

Fig.4 Nusselt number vs Peclet number for inclined flow ($\beta = 60$)

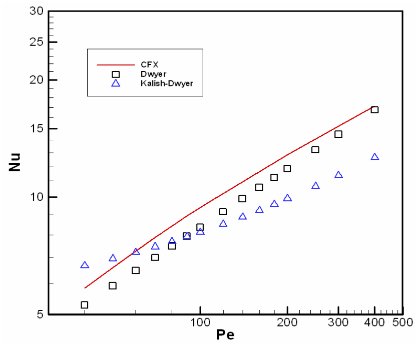

Fig.5 Nusselt number vs Peclet number for inclined flow ($\beta = 30$)

5. Conclusions

A numerical study has been performed to find a better correlation for the design of the 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 correlation by Graber-Rieger best matched the present numerical results. For a cross flow and inclined flows, the correlation by Dwyer works best. It is observed that the Kalish-Dwyer correlation is considered as an improved version of Dwyer's correlation, however, the present calculation shows that the original Dwyer correlation works better than the modified Kalish-Dwyer correlation.

REFERENCES

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