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Evaluation of Pressure Loss and Heat Transfer Correlations for Design of the Intermediate Heat Exchanger in a Sodium Cooled Fast Reactor

Seok-Ki Choi*, Seong-O Kim, Tae-Ho Lee
Fast Reactor Design Division, Korea Atomic Energy Research Institute, 989-111 Daedeokdaero, Yuseong, Daejeon, 305-353, Korea
**Corresponding author: skchoi@kaeri.re.kr*

1. Introduction

The design of the intermediate heat exchanger (IHX) in a sodium cooled fast reactor needs the pressure loss and heat transfer correlations for parallel flow, cross flow and inclined flows. The pressure loss coefficient can be obtained by a water experiment and is relatively abundant in the literatures. However, the experimental heat transfer correlations for sodium are rare since the experiment is very expensive and difficult. This fact leads us to perform CFD calculations to evaluate the previous heat transfer correlations. The existing pressure loss coefficients are evaluated by the water experimental data for cross and inclined flows, while the CFD solutions are used for the evaluation of pressure coefficient for a parallel flow in the present study.

2. Pressure Loss Correlations

2.1 Parallel Flow

The pressure loss correlation for a parallel flow in the IHX design code ASTEEPL[1] is as follows;

$$\Delta P_{parallel} = \frac{1}{2}\rho V_p^2 f_{ti} \frac{l}{d} C_{bun} \quad (1)$$

$$f_{ti} = \begin{cases} \dfrac{64}{\text{Re}} & : \ \text{Re} \le 2000 \\ \dfrac{1}{(1.8\log_{10}\text{Re} - 1.64)^2} & : \ \text{Re} \ge 4000 \\ Interpolation & : \ 2000 \le \text{Re} \le 4000 \end{cases} \quad (2)$$

2.2 Cross and Inclined Flows

-Idelchik correlation;

$$f = \frac{2\Delta P}{\rho U_m^2 N} = \Psi\left(3.2 + 0.66\left(1.7 - \frac{S_1 - d}{S_2^* - d}\right)\right)\text{Re}_m^{-0.27}\frac{N+1}{N} \quad (3)$$

$$\Psi = 0.6135\ln(\theta) - 1.7462\,,\ \text{Re}_m = \frac{\rho U_m d}{\mu} \quad (4)$$

-ESDU correlation

$$f = \frac{2\Delta P d}{\rho U^2 N S_2} = Y\left(\frac{d_v}{d}\right)\frac{1}{(X-1)^2}\Phi \quad (5)$$

$$\left(\frac{d_v}{d}\right) = \frac{2\sqrt{3}X^2}{\pi} - \frac{\text{Re}_U}{\text{Re}_U + 10}\,,\ X = \frac{S_2}{d}\,,\ \text{Re}_U = \frac{\rho U d}{\mu} \quad (6)$$

3. Heat Transfer Correlations

3.1 Parallel Flow

-Graber-Rieger: $Nu = 0.25 + 6.20(p/d) + a(Pe)^b$ (7)

$a = -0.007 + 0.032(p/d)\,,\ b = 0.8 - 0.024(p/d)$ (8)

-Lubarsky-Kaufman: $Nu = 0.625(Pe)^{0.4}$ (9)

-Seban-Shimazaki : $Nu = 5.0 + 0.025(Pe)^{0.8}$ (10)

-Present: $Nu = 0.16 + 4.03(p/d) + a(Pe)^b$ (11)

$a = -0.005 + 0.021(p/d)\,,\ b = 0.8 - 0.024(p/d)$ (12)

3.2 Cross Flow

-Hsu: $Nu = 0.958C(Pe_{v,\max})^{0.5}$, (13)

-Kalish- Dwyer: $Nu = C\left(6.19 + 0.2665[Pe_{v,\max}]^{0.635}\right)$ (14)

-Dwyer: $Nu = C\left(5.36 + 0.1974\,[Pe_{v,\max}]^{0.682}\right)$ (15)

3.3 Inclined Flow

-Kalish-Dwyer: $Nu = D\left(5.44 + 0.228\,[Pe_{v,\max}]^{0.614}\right)$ (16)

-Dwyer: $Nu = 0.958D[Pe_{v,\max}]^{0.5}$ (17)

-Modified-Dwyer: $Nu = D\left(5.36 + 0.1974\,[Pe_{v,\max}]^{0.682}\right)$ (18)

$$\text{where } C = \left(\frac{\phi_1}{d}\right)^{0.5}\left(\frac{p-d}{p}\right)^{0.5},\ D = C\left[\frac{\sin\beta + \sin^2\beta}{1 + \sin^2\beta}\right]^{0.5} \quad (19)$$

4. Results and Discussions

4.1 Evaluation of Pressure Loss Coefficients

Fig.1 shows the comparison of CFD results with the correlation for a parallel flow. Fig.2 and Fig.3 show the comparison of experimental data with the correlations for cross and inclined flows respectively. We can observe that the parallel flow correlation matches well with CFD results by SST turbulence model, while the other high Reynolds number turbulence models under-predict the friction factor. Fig.2 and Fig.3 show that both the Idelchik and ESDU correlations agree well with the experimental data.

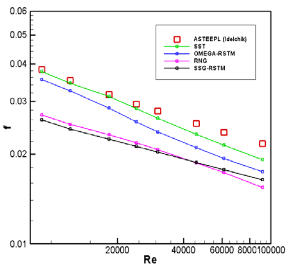


Fig.1 Parallel flow (PL)

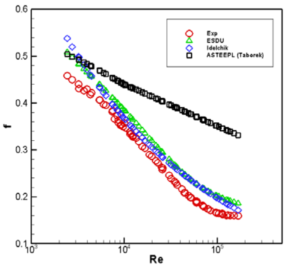
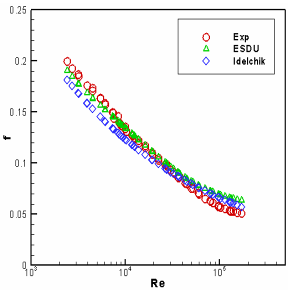
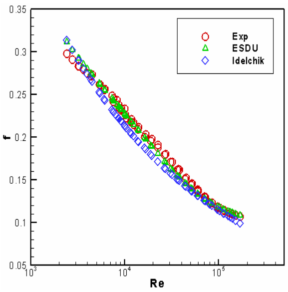


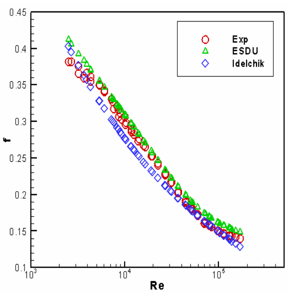
Fig.2 Cross flow (PL)



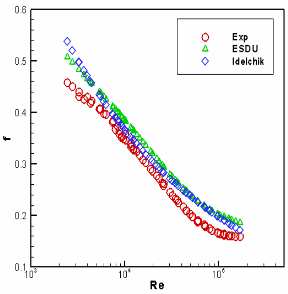
(a) 30°



(b) 45°



(c) 60°

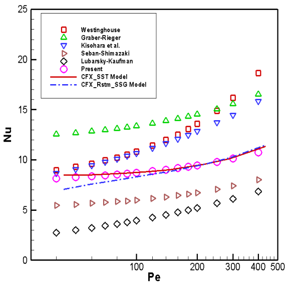


(d) 90°

Fig.3 Inclined flows (PL)

4.2 Evaluation of Heat Transfer Coefficients

Fig.4 shows the predicted average Nusselt number for the parallel flow together with the correlations mentioned above. It is shown that none of the correlations agree with the CFD results. Thus, a new heat transfer correlation for the parallel flow, Eq.(11), based on the CFD results is proposed in the present study. Fig.5 shows the variation of average Nusselt number according to Peclet number for cross flow. It is observed that the Dwyer correlation agrees well with the present results by the SST turbulence model while the Hsu correlation matches with the solution by the RSTM turbulence model. The Hsu correlation is based on several assumptions and is known to be not accurate. Thus, the use of the Dwyer correlation, Eq(15), is recommended for the cross flow. Fig.6 shows that the present CFD results by the SST turbulence model follow the modified Dwyer correlation for flows with 60 and 30 degree inclination. Thus, the use of the modified Dwyer correlation, Eq.(18), for inclined flows is promising.



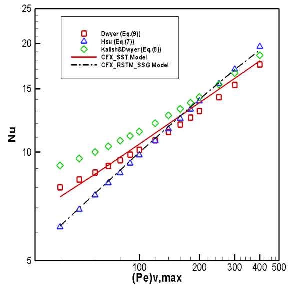
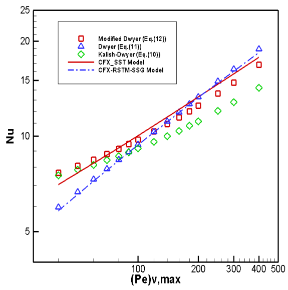
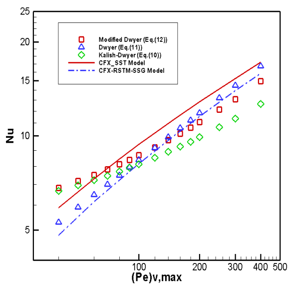


Fig.4 Parallel flow (HT) Fig.5 Cross flow (HT)



(a) 60°



(b) 30°

Fig.6 Inclined flows (HT)

5. Conclusions

An evaluation of pressure loss and heat transfer coefficients is performed. It is shown that the pressure loss coefficient for the parallel flow in the ASTEEPL[1] code is reliable. For the cross and inclined flows, the use of both the Idelchik and ESDU correlations is recommended. For the heat transfer correlations, a new correlation based on the CFD results is proposed for the parallel flow. For the cross flow, the use of Dwyer correlation is recommended and the use of modified Dwyer correlation for the inclined flows is promising.

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.