Single Phase Heat Transfer

Fourier's Law:

$$\vec{q}''(W/m^2) = -k \frac{\partial T}{\partial n} \vec{n} \qquad k\,(W/m\,°K)$$

Newton's Law:

$$\vec{q}''(W/m^2) \equiv h\,(T_w - T_b)\,\vec{n}$$

$$h\,(W/m^2\,°K)$$

Nusselt number

$$Nu \equiv \frac{h D_H}{k} = f(Re, Pr, Gr, \mu_w/\mu_b)$$

$$Pr = \text{Prandtl number} = \frac{\mu c_p}{k}$$

$$Re = \frac{\rho U D_e}{\mu}$$

$$Gr =$$

$$D_H = \frac{4A_F}{P_H} \qquad P_H\text{-heated perimeter.}$$

Table 10-2 Typical h values.

1 Laminar Flow in Tubes: Table 10-4.
Figure 10-6
10-7.

2. Turbulent Flows

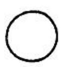
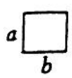
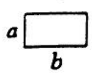
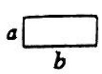
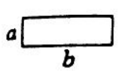
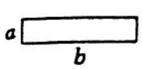
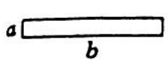
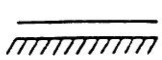
A. Non-metallic fluids.

Turbulent flow: $Nu_\infty = C\, Re^\alpha\, Pr^\beta \cdot \left(\frac{\mu_w}{\mu}\right)^k$

Table 10-2 Typical values of the heat-transfer coefficient for various processes

Process	Heat-transfer coefficient (h) Btu/hr ft^2 °F	W/m^2 °K
Natural convection		
Low pressure gas	1–5	6–28
Liquids	10–100	60–600
Boiling water	100–2000	60–12,000
Forced convection in pipes		
Low pressure gas	1–100	6–600
Liquids		
Water	50–2000	250–12,000
Sodium	500–5000	2,500–25,000
Boiling water	500–10,000	2,500–50,000
Condensation of steam	1,000–20,000	5,000–100,000

Table 10-4 Nusselt number for laminar fully developed velocity and temperature profiles in tubes of various cross sections

Cross-sectional shape	b/a	Nu* $q'' =$ constant	Nu $T_w =$ constant
	—	4.364	3.66
	1.0	3.63	2.98
	1.4	3.78	
	2.0	4.11	3.39
	3.0	4.77	
	4.0	5.35	4.44
	8.0	6.60	5.95
	∞	8.235	7.54
 (insulated)	∞	5.385	4.86
	—	3.00	2.35

Source: From Kays [22].

*The constant-heat-rate solutions are based on constant *axial* heat rate but with constant *temperature* around the tube periphery. Nusselt numbers are averages with respect to tube periphery.

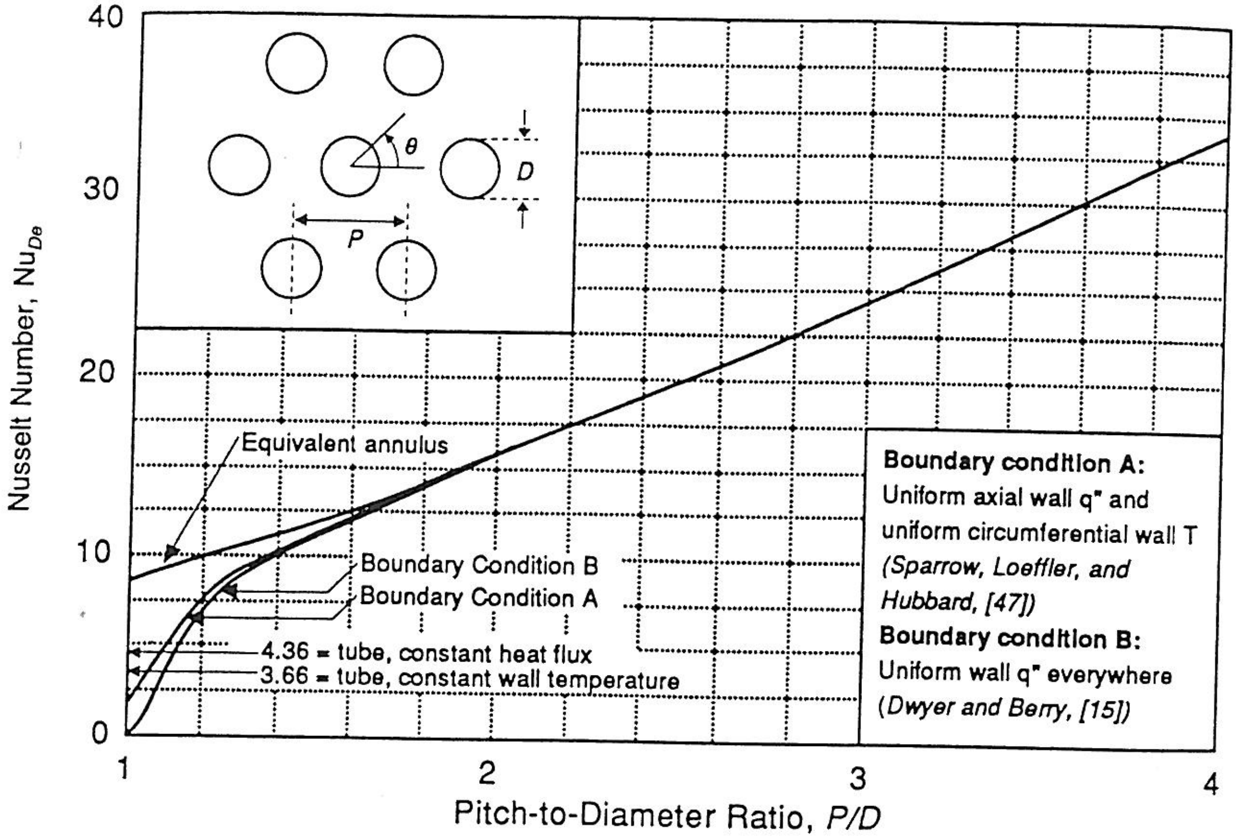


Figure 10-6 Nusselt numbers for fully developed laminar flow parallel to an array of circular tubes.

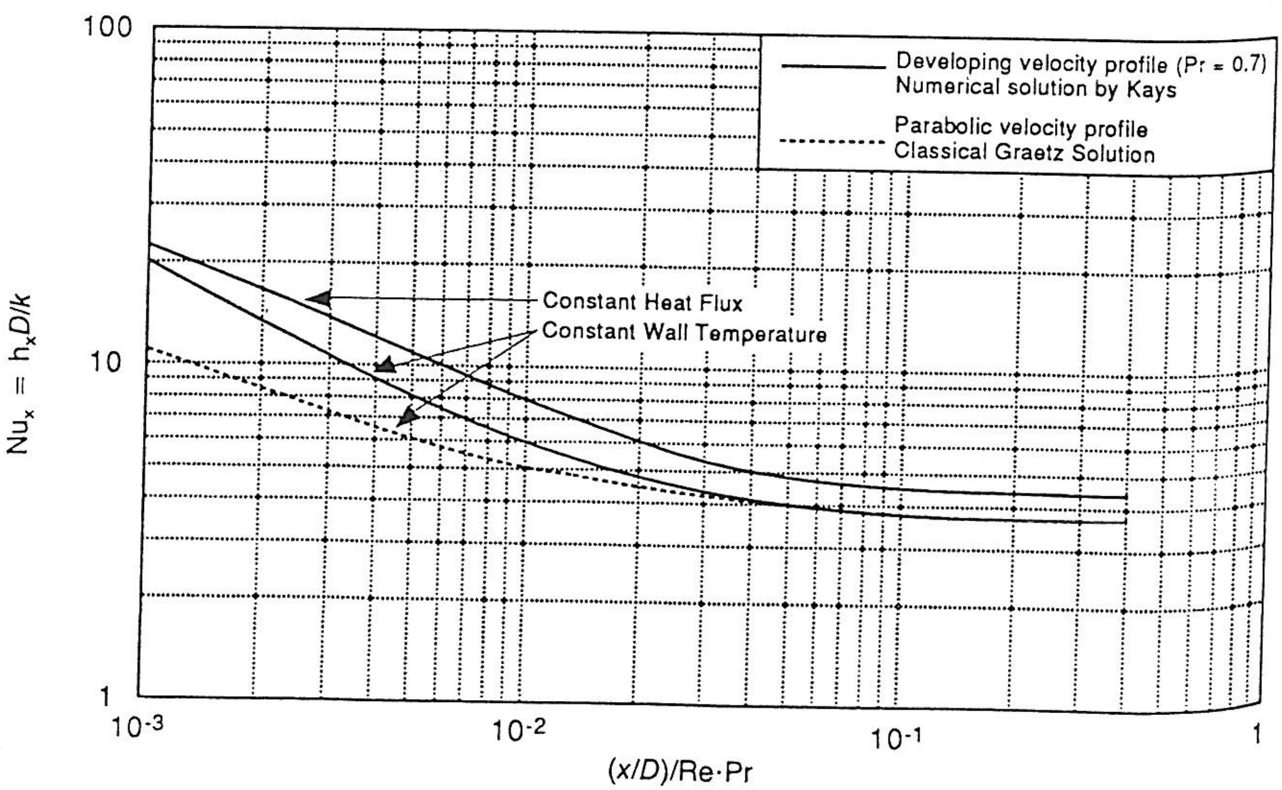


Figure 10-7 Local Nusselt number determined by Kays [23] for simultaneous velocity and temperature development for laminar flow in a circular tube (Pr = 0.7).

Circular Tubes:

i) Seider and Tate: $Nu_\infty = 0.023 Re^{0.8} Pr^{0.4} \left(\frac{\mu_w}{\mu}\right)^{0.14}$.

(bulk temp. except μ_w) $\quad 0.7 < Pr < 120$, $Re > 10{,}000$, $L/D > 60$

ii) Dittus - Boelter: $Nu_\infty = 0.023 Re^{0.8} Pr^{0.4}$ fluid is heated

$Nu_\infty = 0.023 Re^{0.8} Pr^{0.3}$ " " cooled.

(bulk temp.)

iii) Colburn (High viscosity)

$$St\, Pr^{3/2} = 0.023 Re^{-0.2}$$

$$St = Nu/(Re \cdot Pr)$$

(mean film temp.)
cp at bulk temp

Rod bundles: Fig. 10-12, 10-13.

$$Nu_\infty = \psi (Nu_\infty)_{c.t}$$

$$\psi = 0.9090 + 0.0783\, P/D - 0.1283\, e^{-2.4(P/D-1)}$$

Triangular array:
$1.05 \leq P/D \leq 2.2$

$$\psi = 0.9217 + 0.1478\, P/D - 0.1130\, e^{-7(P/D-1)}$$

Square array
$1.05 \leq P/D \leq 1.9$.

B Metallic Fluids:

$Nu_\infty = A + B\, Pe^{C}$; $Pe = Re\, Pr$ - Peclet no.

1 Circular Tube

$Nu_\infty = 7 + 0.025\, Pe^{0.8}$ - constant heat flux

$Nu_\infty = 5.0 + 0.025\, Pe^{0.8}$ - constant wall temp.

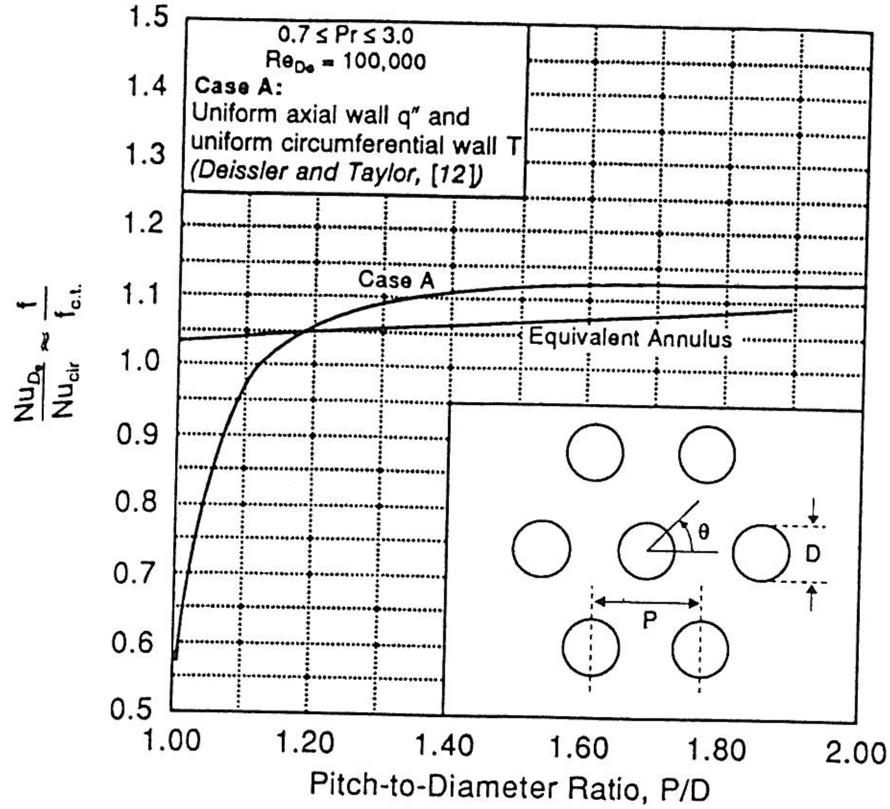


Figure 10-12 Fully developed turbulent flow parallel to a bank of circular tubes or rods. Reynolds number influence is small, and Nusselt number behavior is virtually the same as friction behavior.

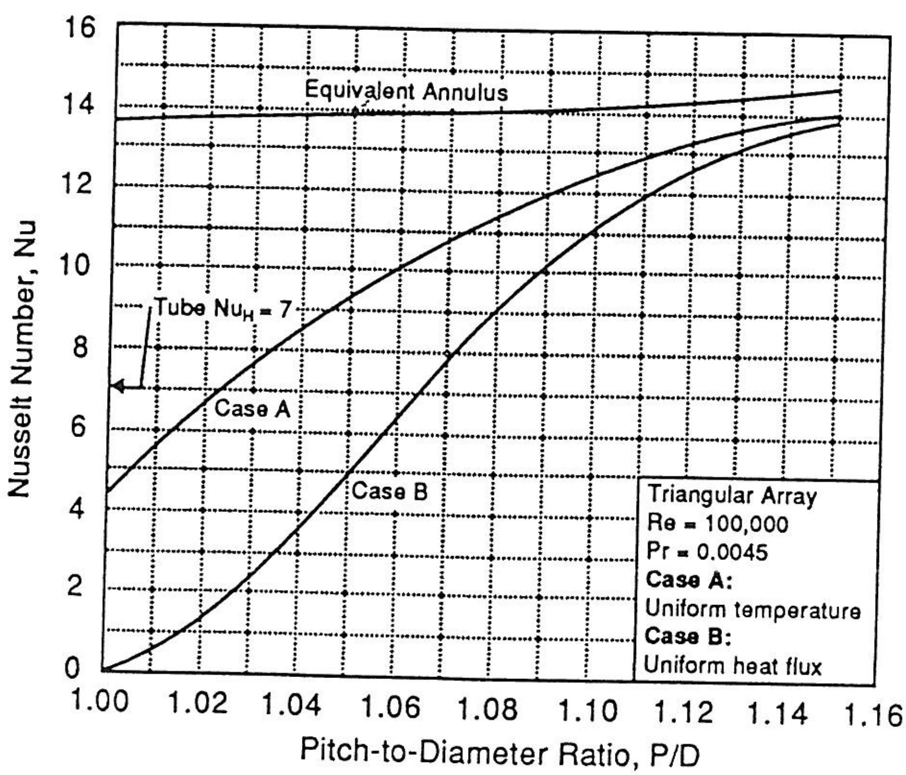


Figure 10-13 Variation of Nusselt number for fully developed turbulent flow with rod spacing for Prandtl number < 0.01. *(From Nijsing [34].)*

2. Parallel plate:

$$Nu_\infty = 5.8 + 0.02\, Pe^{0.8} \quad \text{- constant heat flux}$$

3. Concentric annuli $D_2/D_1 > 1.4$

$$Nu_\infty = 5.25 + 0.0188\, Pe^{0.8} \left(\frac{D_2}{D_1}\right)^{0.3}$$

Rod Bundles.

Fig. 10-16.

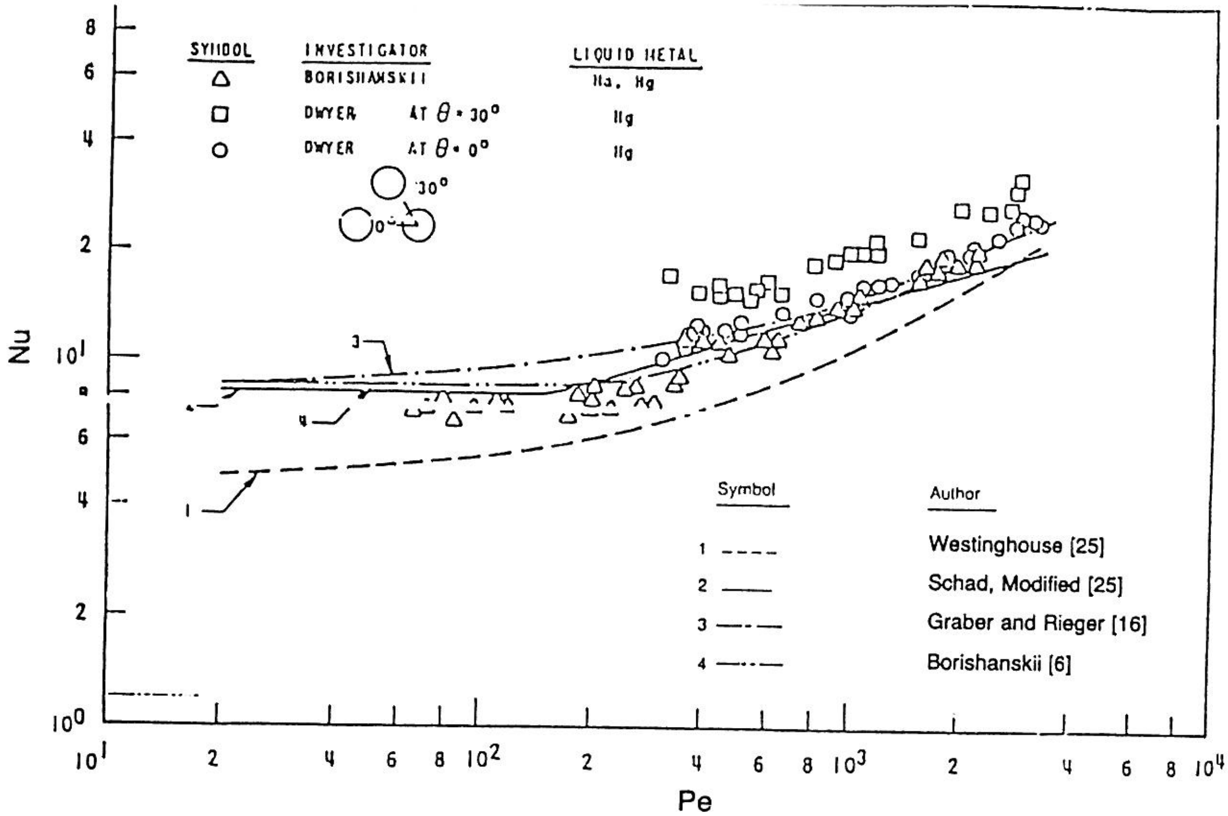


Figure 10-16 Comparison to predicted and experimental results of Nu for liquid metals in rod bundles for $P/D = 1.3$. *(From Kazimi and Carelli* [25].*)*

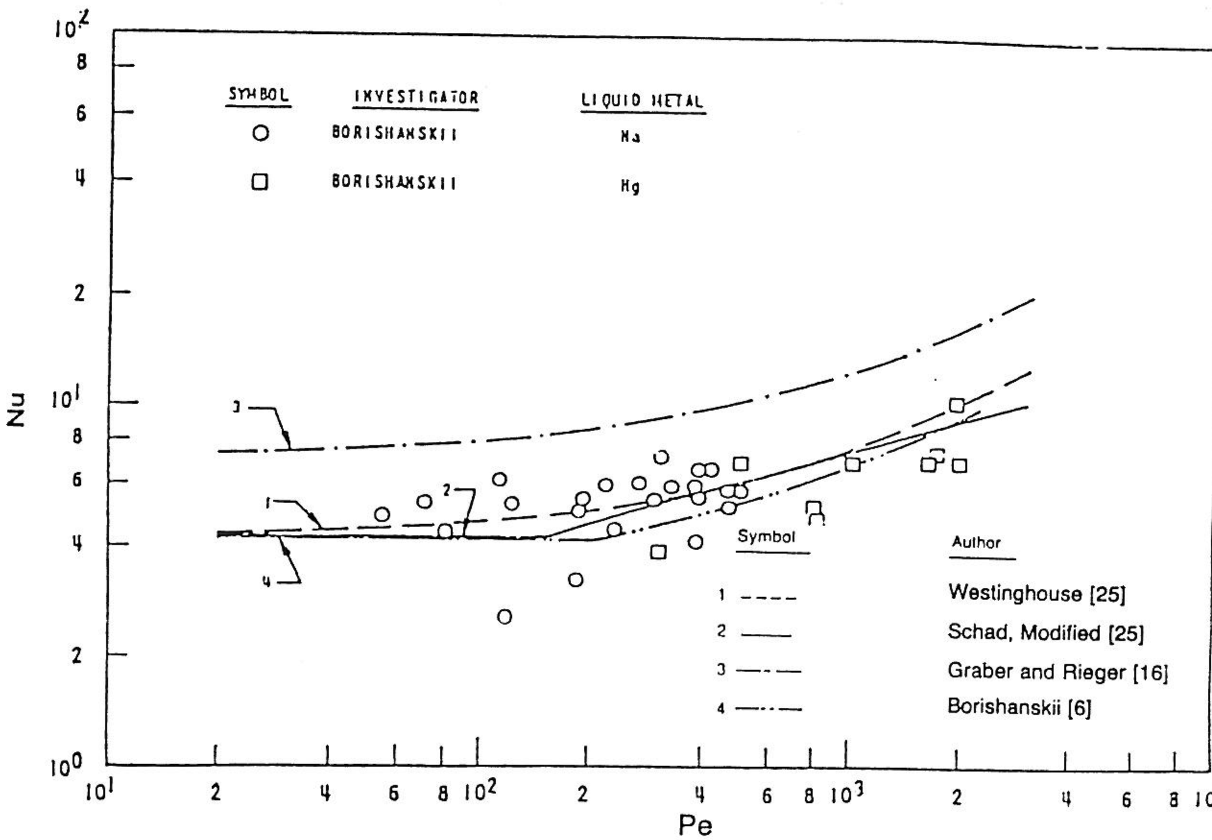


Figure 10-17 Comparison of predicted and experimental results of Nu for metals in rod bundles for $P/D = 1.15$. *(From Kazimi and Carelli* [25].*)*