7.4 **CYLINDER** *in cross flow*

Nusselt Number $\overline{Nu}_D = \dfrac{\bar{h}D}{k}$ **Reynolds Number** $Re_D = \dfrac{VD}{\nu}$

drag coefficient $C_D = \dfrac{F_D}{A_f\left(\rho V^2/2\right)}$ (7.50)   (drag force F_D; frontal area A_f)

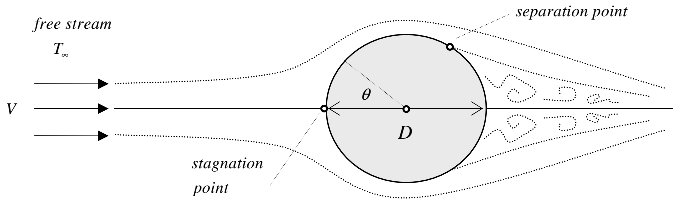
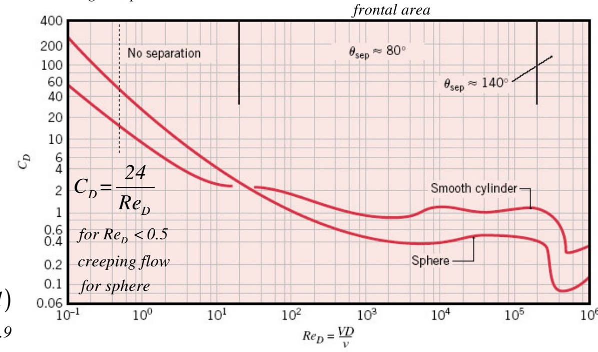


Fig.7.9, p.457



Local Nu_D for stagnation point (for low Re_D)

$$Nu_D\left(\theta=0\right) = 1.15\, Re_D^{1/2}\, Pr^{1/3}$$

$Pr \ge 0.6$ (7.51)

for $0 \le \theta \le \pi$: Fig.7.9

I Hilpert

$$\overline{Nu}_D = C\, Re_D^m\, Pr^{1/3} \qquad (7.52)$$

Re_D	C	m
0.4–4	0.989	0.330
4–40	0.911	0.385
40–4000	0.683	0.466
4000–40,000	0.193	0.618
40,000–400,000	0.027	0.805

all properties at $T_f = \dfrac{T_s + T_\infty}{2}$

$0.4 < Re_D < 4 \cdot 10^5$

$Pr \ge 0.6$

TABLE 7.3 Constants of Equation 7.52 for noncircular cylinders in cross flow of a gas [15]

Geometry	Re_D	C	m
Square ($V \rightarrow$ ◇, D)	5×10^3–10^5	0.246	0.588
Square ($V \rightarrow$ □, D)	5×10^3–10^5	0.102	0.675
Hexagon ($V \rightarrow$, D)	5×10^3–1.95×10^4	0.160	0.638
	1.95×10^4–10^5	0.0385	0.782
Hexagon ($V \rightarrow$, D)	5×10^3–10^5	0.153	0.638
Vertical plate ($V \rightarrow$, D)	4×10^3–1.5×10^4	0.228	0.731

II Churchill

$$\overline{Nu}_D = 0.3 + \frac{0.62\, Re_D^{1/2}\, Pr^{1/3}}{\left[1+\left(\dfrac{0.4}{Pr}\right)^{2/3}\right]^{1/4}}\left[1+\left(\frac{Re_D}{282{,}000}\right)^{5/8}\right]^{4/5} \qquad (7.54)$$

all properties at $T_f = \dfrac{T_s + T_\infty}{2}$

wider range of Re_D and Pr

$Re_D\, Pr \ge 0.2$

III Zhukauskas

$$\overline{Nu}_D = C\, Re_D^m\, Pr^n \left(\frac{Pr}{Pr_s}\right)^{1/4} \qquad (7.53)$$

Re_D	C	m
1–40	0.75	0.4
40–1000	0.51	0.5
10^3–2×10^5	0.26	0.6
2×10^5–10^6	0.076	0.7

$n = 0.37$ for $Pr \le 10$

$n = 0.36$ for $Pr > 10$

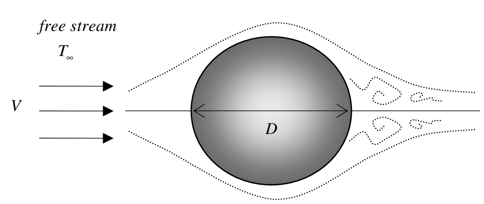
Pr_s at T_s

other properties at T_∞

$0.7 < Pr < 500$

$1 < Re_D < 10^6$

7.5 **SPHERE**



Whitaker

$$\overline{Nu}_D = 2 + \left(0.4\, Re_D^{1/2} + 0.06\, Re_D^{2/3}\right) Pr^{0.4} \left(\frac{\mu}{\mu_s}\right)^{1/4} \qquad (7.56)$$

$0.71 < Pr < 380$

$3.5 < Re_D < 7.6 \cdot 10^4$

$1 < \dfrac{\mu}{\mu_s} < 3.2$

μ_s at T_s

other properties at T_∞

Ranz and Marshall

$$\overline{Nu}_D = 2 + 0.6\, Re_D^{1/2}\, Pr^{1/3} \qquad (7.57)$$

freely falling liquid drops

See Projects Winter 2005: Dan Karpowitz, Jon Day, Ryan Blanchard "Analysis of Convection Correlations for a Cylinder in Laminar Cross Flow"