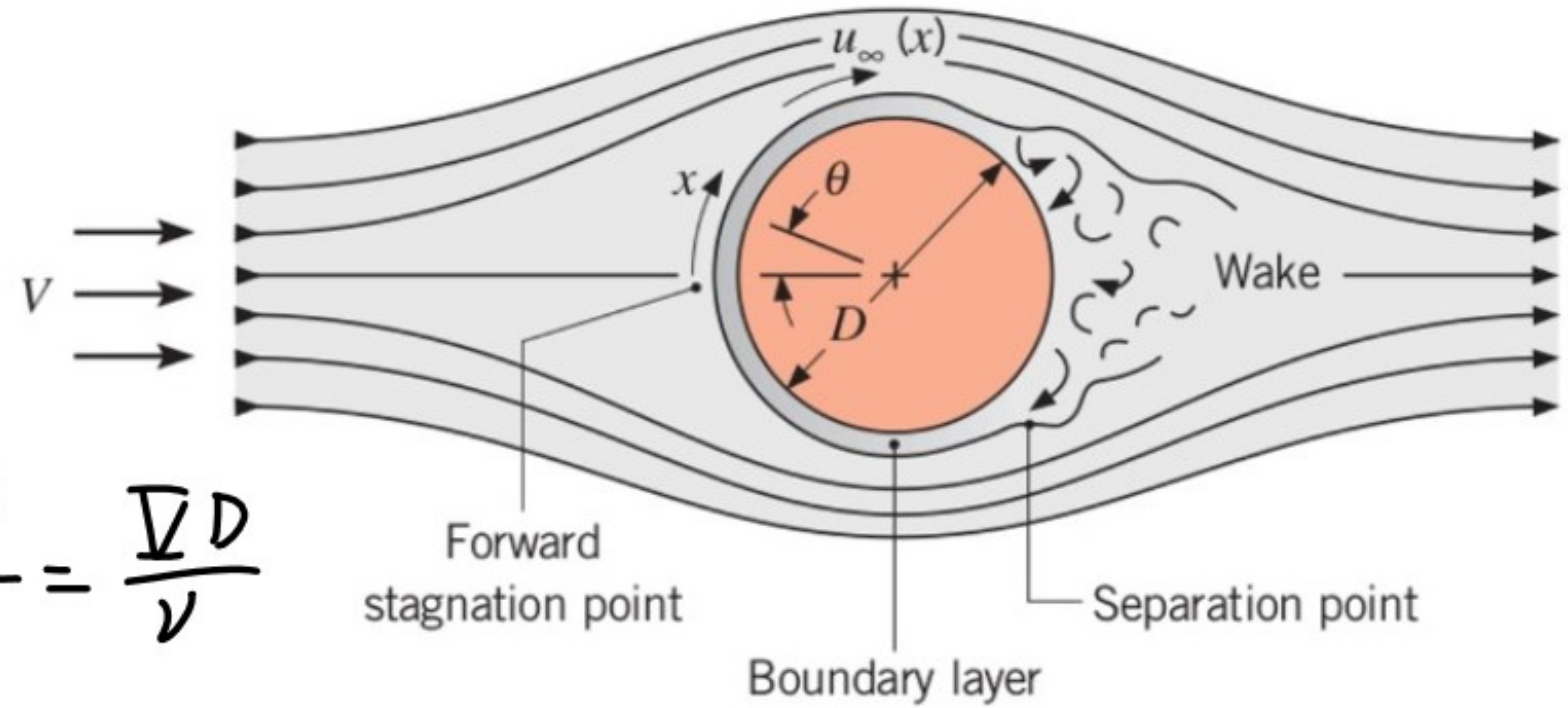
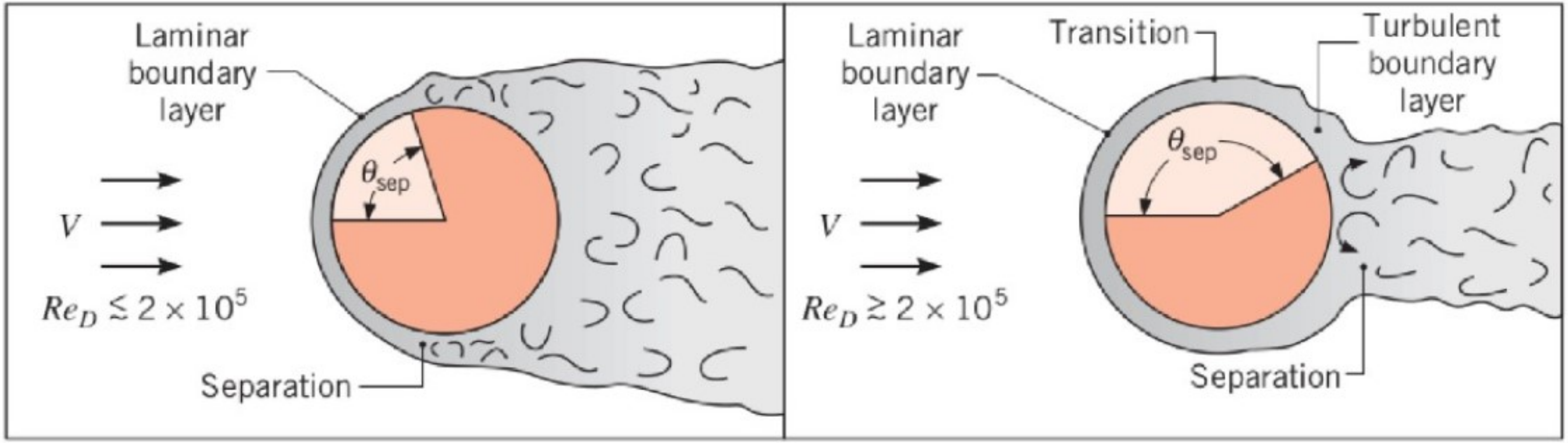
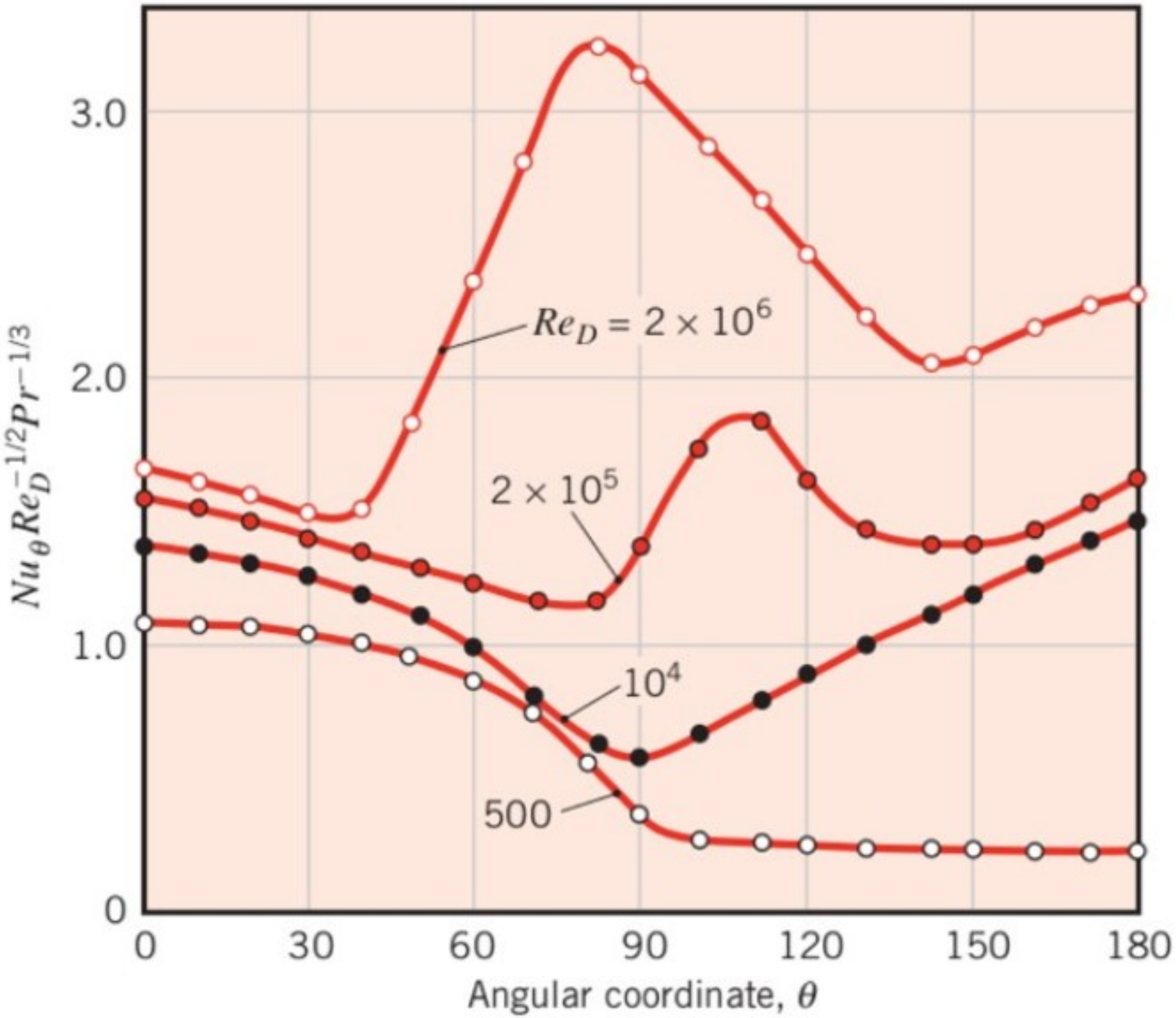
Cylinder in cross flow



$$Re_D = \frac{\rho \mathbb{V} D}{\mu} = \frac{\mathbb{V} D}{\nu}$$

$\mathbb{V}$ fluid velocity


Laminar
boundary
layer
θ_{sep}
V
$Re_D \lesssim 2 \times 10^5$
Separation
Laminar
boundary
layer
Transition
Turbulent
boundary
layer
θ_{sep}
V
$Re_D \gtrsim 2 \times 10^5$
Separation



$Nu_\theta Re_D^{-1/2} Pr^{-1/3}$
3.0
2.0
1.0
0
$Re_D = 2 \times 10^6$
2×10^5
10^4
500
0
30
60
90
120
150
180
Angular coordinate, θ

At low Reynolds Numbers

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

For any Reynolds Number

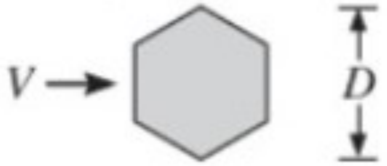
$$\overline{Nu_D} = \frac{\bar{h} D}{k} = C\, Re_D^{m}\, Pr^{1/3} \qquad Pr > 0.7$$

Table 7.2 and 7.3

TABLE 7.2 Constants of Equation 7.52 for the circular cylinder in cross flow [12, 13]

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

TABLE 7.3 Constants of Equation 7.52 for noncircular cylinders in cross flow of a gas [14, 15][a]

Geometry		Re_D	C	m
Square				
		6000–60,000	0.304	0.59
		5000–60,000	0.158	0.66
Hexagon				
		5200–20,400	0.164	0.638
		20,400–105,000	0.039	0.78
		4500–90,700	0.150	0.638
Thin plate perpendicular to flow				
	Front	10,000–50,000	0.667	0.500
	Back	7000–80,000	0.191	0.667

[a] These tabular values are based on the recommendations of Sparrow et al. [15] for air, with extension to other fluids through the $Pr^{1/3}$ dependence of Equation 7.52. A Prandtl number of $Pr = 0.7$ was assumed for the experimental results for air that are described in [15].

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

$0.7 < Pr < 500$

$1 < Re_D < 10^6$

All properties at T_∞

except Pr_s at T_s

Table 7.4

if $Pr < 10$ $n = 0.37$

if $Pr > 10$ $n = 0.36$

TABLE 7.4 Constants of Equation 7.53 for the circular cylinder in cross flow [18]

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

$$\overline{Nu_D} = 0.3 + \frac{0.62\, Re_D^{1/2}\, Pr^{1/3}}{\left(1 + (0.4/Pr)^{2/3}\right)^{1/4}} \left(1 + \left(\frac{Re_D}{282000}\right)^{5/8}\right)^{4/5}$$

$Re_D\, Pr > 0.2$

7.35 An $L = 1$-m-long vertical copper tube of inner diameter $D_i = 20$ mm and wall thickness $t = 2$ mm contains liquid water at $T_w \approx 0°C$. On a winter day, air at $V = 3$ m/s, $T_\infty = -20°C$ is in cross flow over the tube.

(a) Determine the rate of heat loss per unit mass from the water (W/kg) when the tube is full of water.

(b) Determine the rate of heat loss from the water (W/kg) when the tube is half full.

$$Re_D = \frac{V D}{\nu} = \frac{3\,\text{m/s} \quad 0.024\,\text{m}}{11.4\times10^{-6}\,\text{m}^2/\text{s}}$$

$$= 6316$$

$$\overline{Nu}_D = C\,Re_D^{\,m}\,Pr^{1/3} = 0.193\,(6316)^{0.698}\,0.72^{1/3} = \frac{\bar{h} D}{k}$$