# Chapter 6 of Heinsohn & Cimbala: Useful Figures and Tables

John M. Cimbala, Penn State University. Latest update: 30 October 2017

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**Table 6.1** Capture velocities (abstracted from ACGIH, 2001).

| **characteristics of contaminant emission** | **examples** | **capture velocity (FPM)** |
|---|---|---|
| 1. contaminant enters quiescent air with negligible velocity | degreasing tank, evaporation | 50-100 |
| 2. contaminant enters slightly moving air with a low velocity | welding, vessel filling | 100-200 |
| 3. contaminant actively generated and enters rapidly moving air | spray painting, stone crushers | 200-500 |
| 4. contaminant air enters rapidly at high velocity | grinding, abrasive blasting | 500-2000 |

<u>Lower values of capture velocity</u>:

- room air movement minimal or conducive to capture
- contaminants of low toxicity
- intermittent use or low production rates
- large hood and large mass of air moved

<u>Upper values of capture velocity</u>:

- adverse room air movement
- contaminants of high toxicity
- heavy use and high production rates
- small hood and small mass of air moved

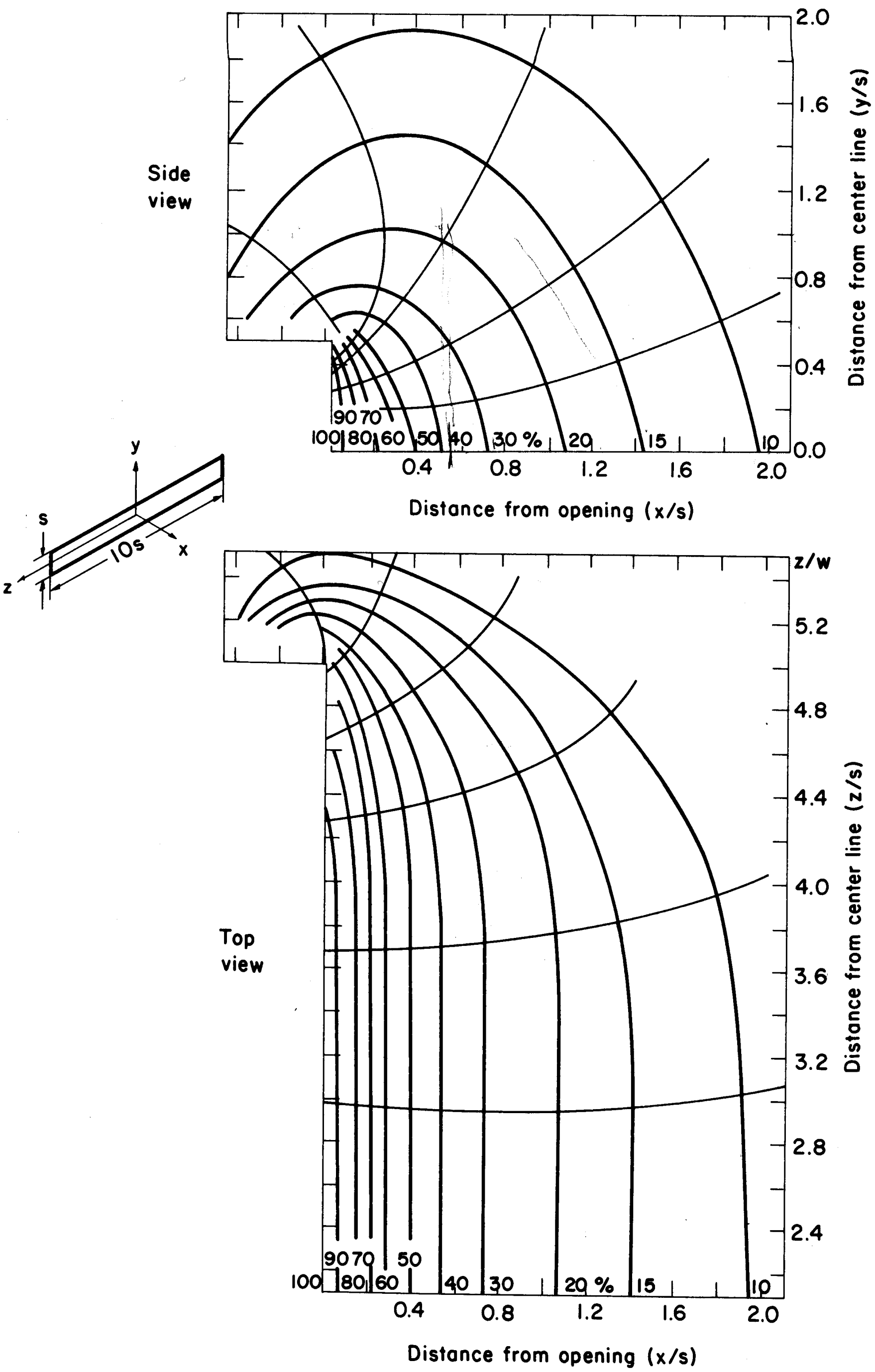

**Figure 6.8** Velocity isopleths (curves of constant $U/U_{face}$, %) for an unflanged rectangular opening, aspect ratio 1:10 (adapted from Baturin, 1972).

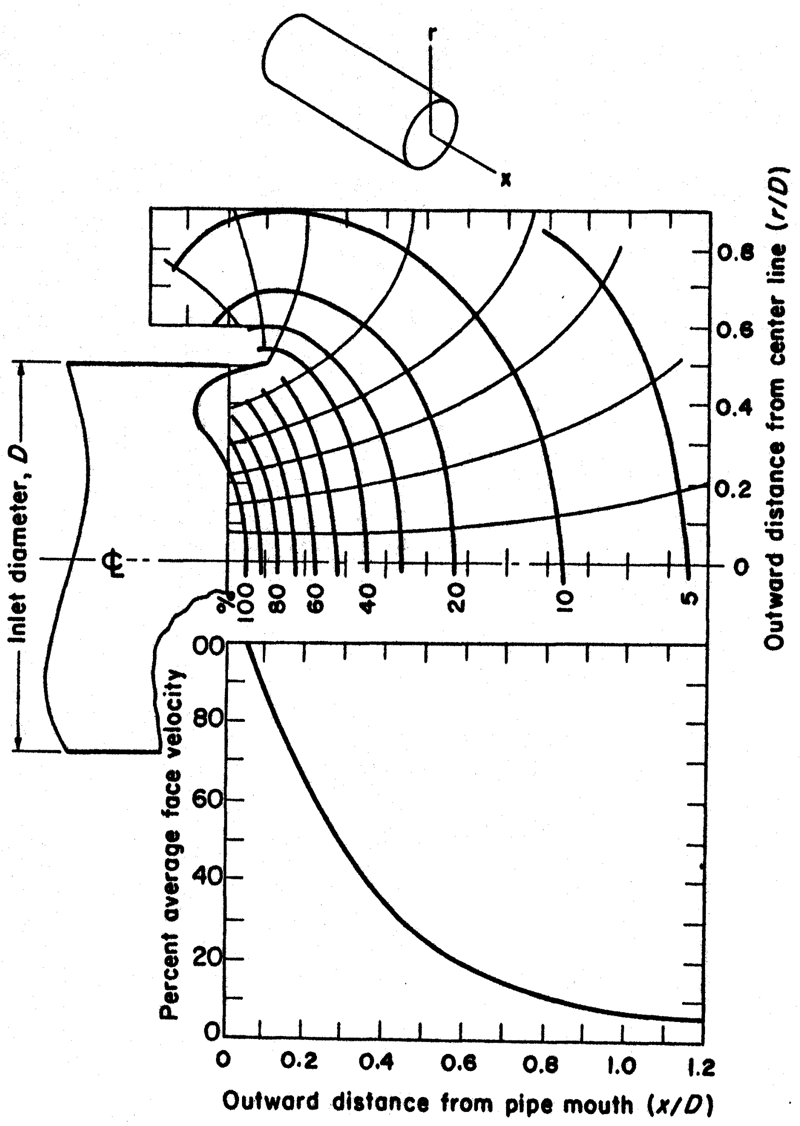

**Figure 6.9** Velocity isopleths (curves of constant $U/U_{face}$, %) and decay of $U(x,0)/U_{face}$ (along the centerline, %) for a plain circular opening (adapted from ASHRAE HVAC Applications Handbook, 1995).

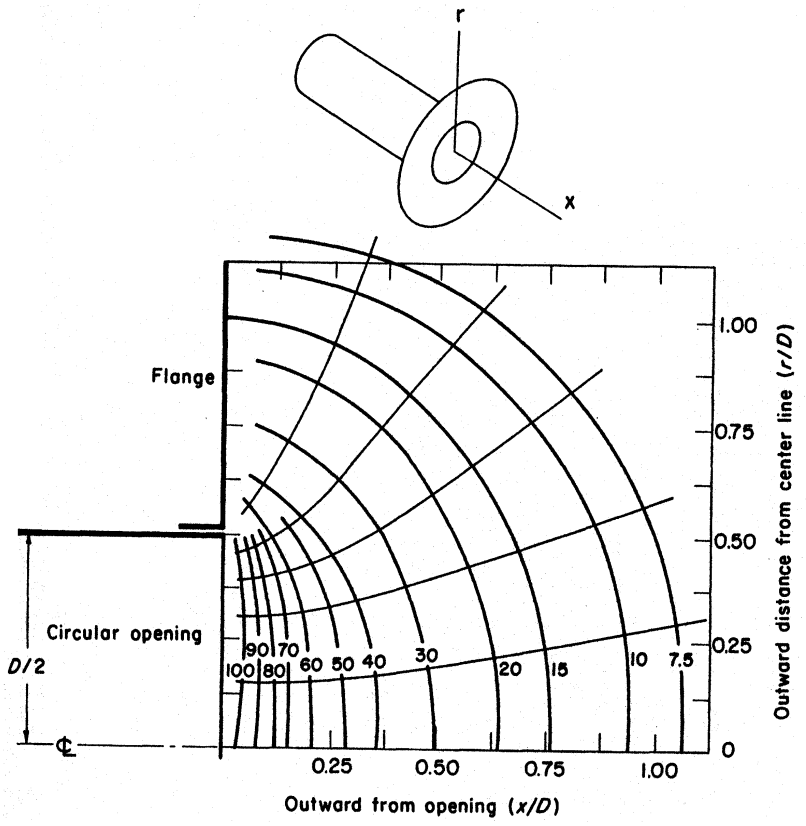

**Figure 6.10** Velocity isopleths (curves of constant $U/U_{\text{face}}$, %) for a flanged circular opening (adapted from ASHRAE HVAC Applications Handbook, 1995).

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**Table 6.2** Hazard potential and rate of contaminant evolution (abstracted from ACGIH, 2001).

| hazard potential | health standard for gas or vapor (PPM) | health standard for mist (mg/m$^3$) | flash point (°F) |
|---|---|---|---|
| A | 0 to 10 | 0 to 0.1 | - |
| B | 11 to 100 | 0.11 to 1.0 | under 100 |
| C | 101 to 500 | 1.1 to 10 | 100 to 200 |
| D | over 500 | over 10 | over 200 |

| rate | liquid temperature (°F) | degrees below boiling (°F) | evaporation time[1] (hr) | gassing[2] |
|---|---|---|---|---|
| 1 | over 200 | 0 to 20 | 0 to 3 (fast) | high |
| 2 | 150 to 200 | 21 to 50 | 3 to 12 (medium) | medium |
| 3 | 94 to 149 | 51 to 100 | 12 to 50 (slow) | low |
| 4 | under 94 | over 100 | over 50 (nil) | nil |

[1] time for 100% evaporation

[2] extent to which gas or vapor are generated: rate depends on the physical process and the solution concentration and temperature

**Table 6.3** Minimum control velocities (FPM) for undisturbed locations (abstracted from ACGIH, 2001).

| class | enclosing hood | | lateral hood[1] | canopy hood[4] | |
|---|---|---|---|---|---|
| | 1 side open | 2 sides open | | 3 sides open | 4 sides open |
| A1[2], A2[2] | 100 | 150 | 150 | do not use | do not use |
| A3[2], B1, B2, C1 | 75 | 100 | 100 | 125 | 175 |
| B3[3], C2[3], D1[3] | 65 | 90 | 75 | 100 | 150 |
| A4[2], C3[3], D2[3] | 50 | 75 | 50 | 75 | 125 |
| B4, C4, D3[3], D4 | adequate general room ventilation required | | | | |

[1] use Table 6.4 to compute the volumetric flow rate

[2] do not use a canopy hood for hazard potential A processes

[3] where complete control of hot water is desired, design as next highest class

[4] use $Q = 1.4(PD)$ control velocity, where $P$ is hood perimeter and $D$ is distance between vessel and hood face

**Table 6.4** Minimum volumetric flow rates per unit surface area (CFM/ft$^2$) for lateral exhaust systems (abstracted from ACGIH, 2001).

| control velocity (FPM) | [2]aspect ratio = tank width/tank length (*W*/*L*) | | | | |
|---|---|---|---|---|---|
| | 0 - 0.09 | 0.1 - 0.24 | 0.25 - 0.49 | 0.5 - 0.99 | 1.0 - 2.0 |
| **tank against wall or baffled[1]** | | | | | |
| 50 | 50 | 60 | 75 | 90 | 100 |
| 75 | 75 | 90 | 110 | 130 | 150 |
| 100 | 100 | 125 | 150 | 175 | 200 |
| 150 | 150 | 190 | 225 | 250[3] | 250[3] |
| **free-standing tank[1]** | | | | | |
| 50 | 75 | 90 | 100 | 110 | 125 |
| 75 | 110 | 130 | 150 | 170 | 190 |
| 100 | 150 | 175 | 200 | 225 | 250 |
| 150 | 225 | 250[3] | 250[3] | 250[3] | 250[3] |

[1] use half width to compute $W/L$ for inlet along tank centerline or two parallel sides of tank

[2] inlet slot along the long side ($L$); if $6 < L < 10$ ft, multiple takeoffs are desirable; if $L > 10$ ft, multiple takeoffs in plenum are necessary if:

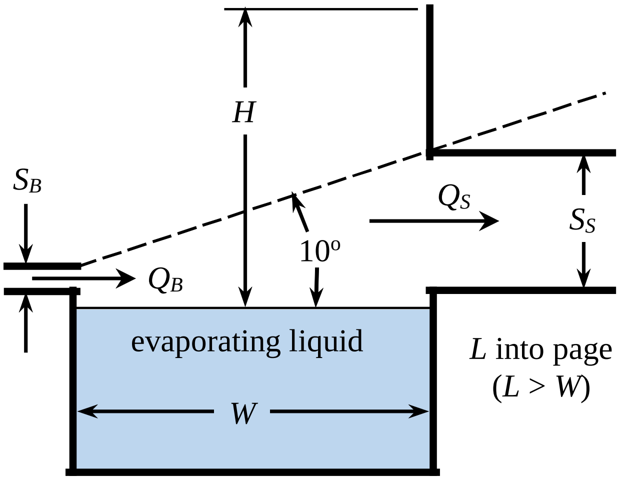
- $W = 20$ inches: slot on one side is suitable
- $20 < W < 36$ inches: slots on both sides are desirable
- $36 < W < 48$ inches: slots on both sides are necessary unless all other conditions are optimum
- $W > 48$ inches: lateral exhausts are not usually practical, use push-pull or enclosures
- it is undesirable to use lateral exhaust when $W/L > 1$ and not practical when $W/L > 2$

[3] while control velocities of 150 FPM may not be achieved, 250 CFM/ft$^2$ is considered adequate for control

**Table 6.5** Metal surface treatment processes (adapted from ACGIH, 2001).

| **process** | **bath** | **emission**[1] | ***T* (°F)** | **class** |
|---|---|---|---|---|
| **anodizing:** | | | | |
| aluminum | $H_2SO_4$ | $H_2$, acid mist | 60-80 | B1 |
| **etching:** | | | | |
| aluminum | NaOH, $NA_2CO_3$, $Na_3PO_4$ | alkaline mist | 160-180 | C1 |
| copper | HCl | HCl | 70-90 | A2 |
| **pickling:** | | | | |
| aluminum | $HNO_3$ | oxides of nitrogen | 70-90 | A2 |
| copper | $H_2SO_4$ | acid mist, steam | 125-175 | B3, B2 |
| monel & nickel | HCl | acid mist, steam | 180 | A2 |
| stainless | $H_2SO_4$ | acid mist, steam | 180 | B1 |
| **cleaning:** | | | | |
| alkaline | sodium salts | alkaline mist | 160-210 | C2, C1 |
| degreasing | trichloroethylene | vapor | 188-250 | B |
| degreasing | perchloroethylene | vapor | 188-250 | B |
| **electroplating:** | | | | |
| platinum | $NH_4PO_4$ & $NH_3(g)$ | $NH_3(g)$ | 158-203 | B2 |
| copper | NaOH, cyanide salts | cyanide, alkaline | 110-160 | C2 |
| chromium | chromic acid | chromic acid mist | 90-140 | A1 |
| nickel | HF, $NH_4F$ | acid mist | 102 | A3 |
| **stripping:** | | | | |
| gold | $H_2SO_4$ | acid mist | 70-100 | B3, B2 |
| nickel | HCl | acid mist | 70-90 | A3 |
| silver | $HNO_3$ | oxides of nitrogen | 70-90 | A1 |

[1] at high temperature, an alkaline or acid bath produces a mist of similar composition

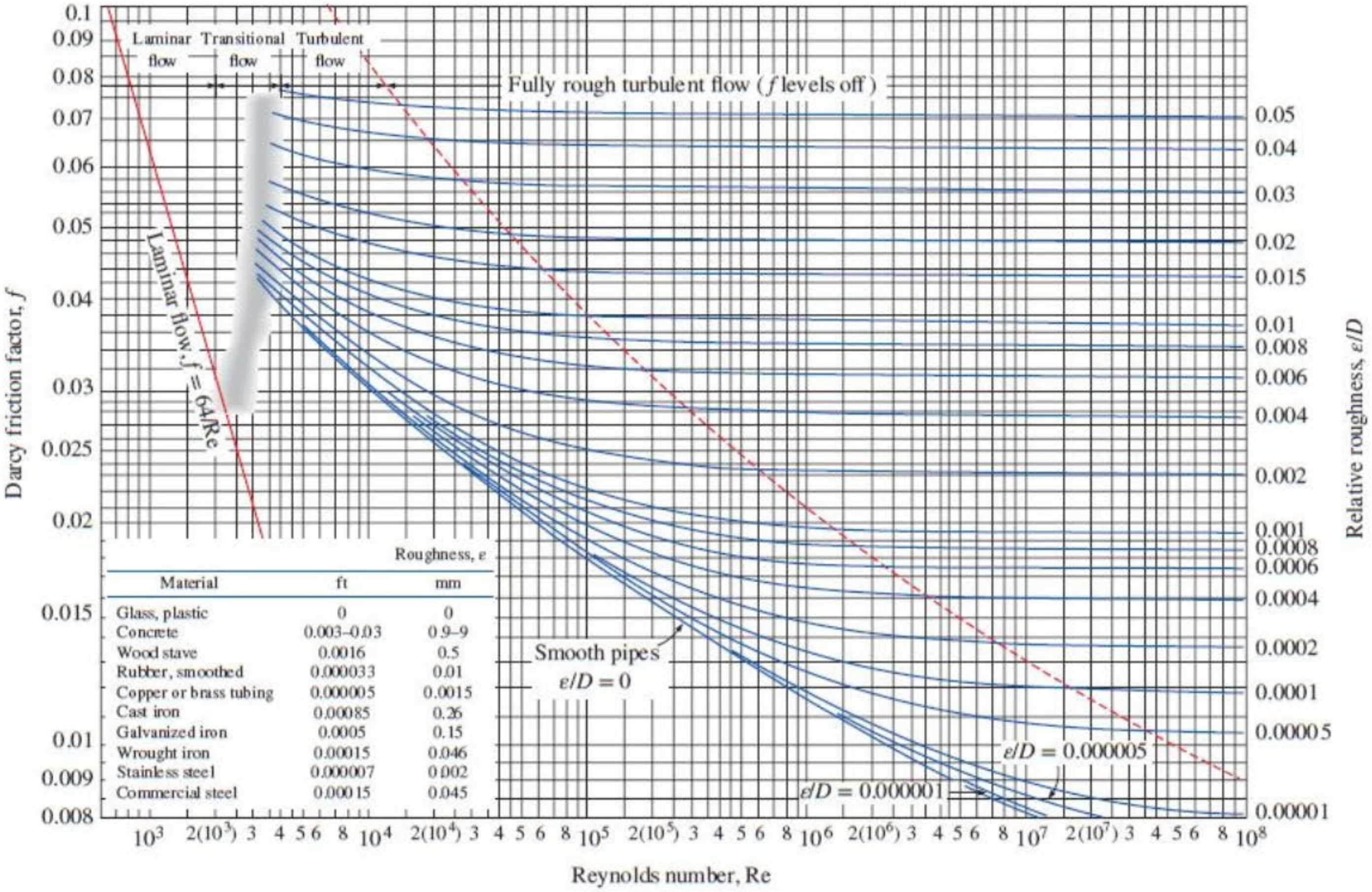


**blowing jet area** ($A_B$, ft$^2$)
**blowing plenum cross sectional area** > $3A_B$
**blowing slot width** ($S_B$, in): 1/8" ≤ $S_B$ ≤ 1/4" or, 1/4" diameter holes, spaced holes 3/4" to 2" apart
**blowing volumetric flow rate**: $Q_B/L = 243(A_B/L)^{0.5}$ ACFM/ft, where $A_B/L$ is in units of (ft$^2$/ft)
**suction opening**: $A_S = LS_S$ ft$^2$
**suction slot width**: $S_S = 0.14$ W
**suction volumetric flow rate**: depends on liquid temperature, i.e.,
$T \leq 150$ °F, $Q_S/LW = 75.$ ACFM/ft$^2$
$T > 150$ °F, $Q_S/LW = [0.40\text{T(°F)} + 15.]$ ACFM/ft$^2$

**Figure 6.13** Push pull ventilation system for an open surface vessel for widths up to 10 ft (abstracted from ACGIH, 1988 and 1998).

## Friction factor for major losses (losses in long straight sections of pipe or duct):

**Graphical estimate – the Moody Chart:** [Figure from Cengel and Cimbala, Fluid Mechanics: Fundamentals and Applications, Ed. 4.]



| | Roughness, $\varepsilon$ | |
|---|---|---|
| Material | ft | mm |
| Glass, plastic | 0 | 0 |
| Concrete | 0.003–0.03 | 0.9–9 |
| Wood stave | 0.0016 | 0.5 |
| Rubber, smoothed | 0.000033 | 0.01 |
| Copper or brass tubing | 0.000005 | 0.0015 |
| Cast iron | 0.00085 | 0.26 |
| Galvanized iron | 0.0005 | 0.15 |
| Wrought iron | 0.00015 | 0.046 |
| Stainless steel | 0.000007 | 0.002 |
| Commercial steel | 0.00015 | 0.045 |

**FIGURE A–12**

The Moody chart for the friction factor for fully developed flow in circular pipes for use in the head loss relation $h_L = f\frac{L}{D}\frac{V^2}{2g}$. Friction factors in the turbulent flow are evaluated from the Colebrook equation $\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right)$.

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**Empirical equation – the Churchill Equation:** $\boxed{f = 8\left[\left(\frac{8}{\mathrm{Re}}\right)^{12} + \left(A+B\right)^{-1.5}\right]^{\frac{1}{12}}}$, where

$\boxed{A = \left\{-2.457\cdot\ln\left[\left(\frac{7}{\mathrm{Re}}\right)^{0.9} + 0.27\frac{\varepsilon}{D}\right]\right\}^{16}}$ and $\boxed{B = \left(\frac{37530}{\mathrm{Re}}\right)^{16}}$. **Darcy friction factor**, $\boxed{h_{L,\mathrm{major}} = f\,\frac{L}{D}\frac{V^2}{2g}}$.

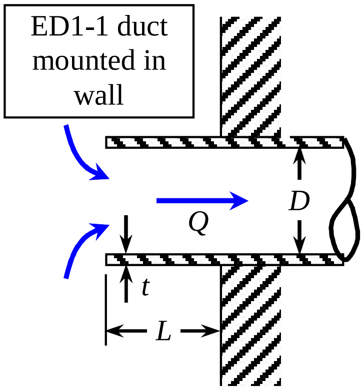
For non-circular ducts, use **hydraulic diameter**, $\boxed{D_h = \frac{4A_c}{p}}$, where $A_c$ is the cross-sectional area of the duct and $p$ is the wetted perimeter (always the entire perimeter for air flows).

# Minor Loss Coefficients for various entrances, elbows, and expansions:

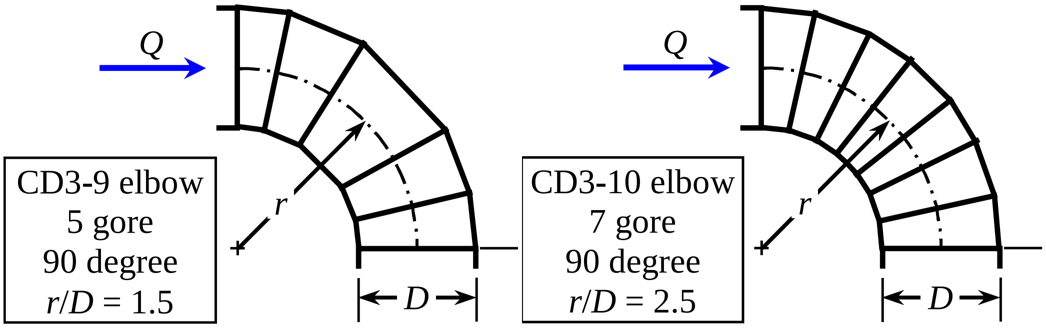
*Note*: We use $K_L$ as the minor loss coefficient in fluids class, but in HVAC we use $C_0$. $K_L = C_0$.

**loss coefficient $C_0$ for round duct mounted in wall**

| ***t/D*** | ***L/D*** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **0.00** | **0.01** | **0.05** | **0.10** | **0.20** | **0.30** | **0.50** | **10.0** |
| **0.00** | 0.50 | 0.68 | 0.80 | 0.86 | 0.92 | 0.97 | 1.00 | 1.00 |
| **0.02** | 0.50 | 0.52 | 0.55 | 0.60 | 0.66 | 0.69 | 0.72 | 0.72 |
| **0.05** | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| **10.0** | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |



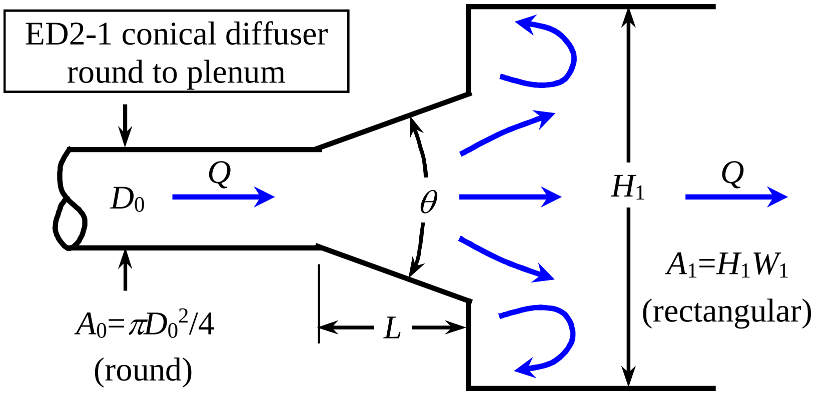
(a)



| ***D* (mm)** | **75** | **150** | **230** | **300** | **380** | **450** | **530** | **600** | **690** | **750** | **1500** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **$C_0$, CD3-9** | 0.51 | 0.28 | 0.21 | 0.18 | 0.16 | 0.15 | 0.14 | 0.13 | 0.12 | 0.12 | 0.12 |
| **$C_0$, CD3-10** | 0.16 | 0.12 | 0.10 | 0.08 | 0.07 | 0.06 | - | - | 0.05 | - | 0.03 |

(b)

**Figure 6.29** Fitting loss coefficients: (a) duct mounted in a wall (also called a ***re-entrant inlet***); (b) round 90-degree elbows: 5 gore, $r/D = 1.5$ and 7 gore, $r/D = 2.5$ (abstracted from ASHRAE Fundamentals Handbook, 1997).



**loss coefficient $C_0$ at listed values of $A_1/A_0$ and $L/D_0$**

| $A_1/A_0$ | $L/D_0$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **2.0** | **3.0** | **4.0** | **5.0** | **6.0** | **8.0** | **10.0** | **12.0** | **14.0** |
| **1.5** | 0.03 | 0.03 | 0.04 | 0.05 | 0.06 | 0.08 | 0.10 | 0.11 | 0.13 |
| **2.0** | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.06 | 0.08 | 0.09 | 0.10 |
| **2.5** | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.07 | 0.08 | 0.09 |
| **3.0** | 0.09 | 0.07 | 0.07 | 0.06 | 0.06 | 0.07 | 0.07 | 0.08 | 0.08 |
| **4.0** | 0.12 | 0.10 | 0.09 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 |
| **6.0** | 0.16 | 0.13 | 0.12 | 0.10 | 0.10 | 0.09 | 0.09 | 0.09 | 0.08 |
| **8.0** | 0.18 | 0.15 | 0.13 | 0.12 | 0.11 | 0.10 | 0.09 | 0.09 | 0.09 |
| **10.0** | 0.20 | 0.16 | 0.14 | 0.13 | 0.12 | 0.11 | 0.10 | 0.09 | 0.09 |
| **20.0** | 0.24 | 0.20 | 0.17 | 0.15 | 0.14 | 0.12 | 0.11 | 0.11 | 0.10 |

**optimum value of angle $\theta$ (degrees) at listed values of $A_1/A_0$ and $L/D_0$**

| $A_1/A_0$ | $L/D_0$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **2.0** | **3.0** | **4.0** | **5.0** | **6.0** | **8.0** | **10.0** | **12.0** | **14.0** |
| **1.5** | 13 | 9 | 7 | 6 | 4 | 3 | 2 | 2 | 2 |
| **2.0** | 17 | 12 | 10 | 9 | 8 | 6 | 5 | 4 | 3 |
| **2.5** | 20 | 15 | 12 | 11 | 10 | 8 | 7 | 6 | 5 |
| **3.0** | 22 | 17 | 14 | 12 | 11 | 10 | 8 | 8 | 6 |
| **4.0** | 26 | 20 | 16 | 14 | 13 | 12 | 10 | 10 | 9 |
| **6.0** | 28 | 22 | 19 | 16 | 15 | 12 | 11 | 10 | 9 |
| **8.0** | 30 | 24 | 20 | 18 | 16 | 13 | 12 | 11 | 10 |
| **10.0** | 30 | 24 | 22 | 19 | 17 | 14 | 12 | 11 | 10 |
| **20.0** | 32 | 26 | 22 | 20 | 18 | 15 | 13 | 12 | 11 |

**Figure 6.30** Fitting loss coefficients for an ED2-1 conical diffuser (abstracted from ASHRAE Fundamentals Handbook, 1997).