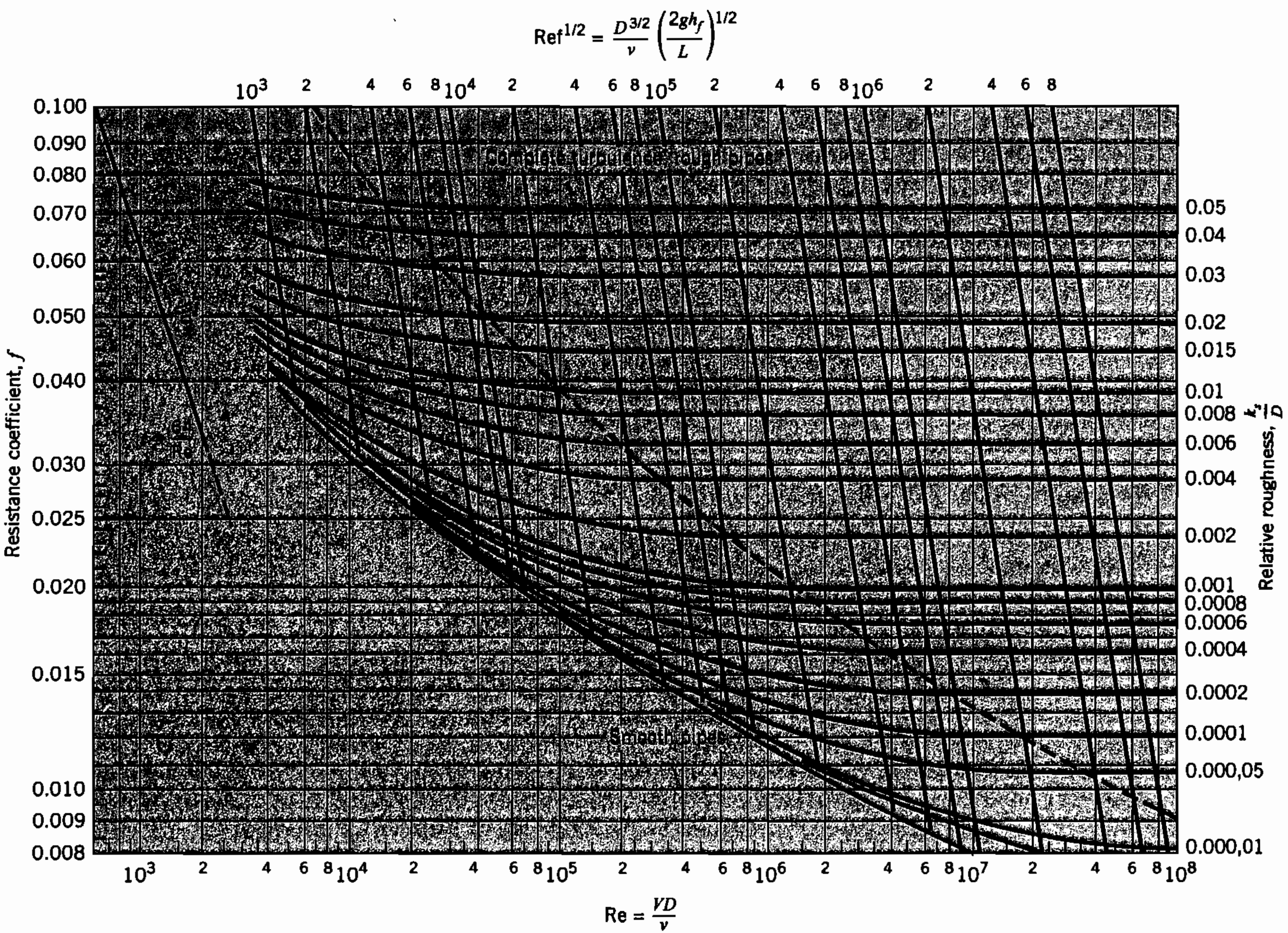

$Re f^{1/2} = \frac{D^{3/2}}{\nu}\left(\frac{2gh_f}{L}\right)^{1/2}$
Complete turbulence, rough pipes
Smooth pipes
$\frac{64}{Re}$
Resistance coefficient, f
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.025
0.020
0.015
0.010
0.009
0.008
Relative roughness, $\frac{k_s}{D}$
0.05
0.04
0.03
0.02
0.015
0.01
0.008
0.006
0.004
0.002
0.001
0.0008
0.0006
0.0004
0.0002
0.0001
0.000,05
0.000,01
$Re = \frac{VD}{\nu}$

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FRICTION FACTOR FOR TURBULENT PIPE FLOW

TABLE 4.2 Fully Developed Turbulent Flow Friction Factor Correlations for a $\boxed{\text{Smooth}}$ Circular Duct

Investigators	Correlation	Recommended Re Range	Remarks
Blasius [48]	$f = 0.0791\,Re^{-0.25}$	4×10^3 to 10^5	Within +2.6% and −1.3% of PKN (see below)
McAdams [64]	$f = 0.046\,Re^{-0.2}$	3×10^4 to 10^6	Within +2.6% and −0.4% of PKN
Present authors	$f = 0.0366\,Re^{-0.1818}$	4×10^4 to 10^7	Within +2.4% and −3% of PKN
Nikuradse [50]	$f = 0.0008 + 0.0553\,Re^{-0.237}$	10^5 to 10^7	Within −2% of PKN
Drew et al. [61]	$f = 0.0014 + 0.125\,Re^{-0.32}$	4×10^3 to 5×10^6	Within +3% of PKN
Present authors	$f = 0.00128 + 0.1143\,Re^{-0.311}$	4×10^3 to 10^7	Within +1.2% and −2% of PKN
Prandtl [62], Kármán [63], Nikuradse [50] (PKN)	$\frac{1}{\sqrt{f}} = 1.7372 \ln(Re\sqrt{f}) - 0.3946$	4×10^3 to 10^7	Classical correlation, here called PKN, has a theoretical basis and is valid for arbitrarily large Re. Its predictions agree with the extensive experimental measurements within ±2%.
Colebrook [65]	$\frac{1}{\sqrt{f}} = 1.5635 \ln\left(\frac{Re}{7}\right)$	4×10^3 to 10^7	Mathematical approximation to PKN, yielding numerical values within ±1% of PKN
Filonenko [66]	$\frac{1}{\sqrt{f}} = 1.58 \ln Re - 3.28$	10^4 to 10^7	Within ±1.8% of PKN
Techo et al. [67]	$\frac{1}{\sqrt{f}} = 1.7372 \ln \frac{Re}{1.964 \ln Re - 3.8215}$	10^4 to 10^7	Explicit form of PKN; agrees within ±0.1%

$$\epsilon = k_s \qquad a = \frac{D}{2}$$

TABLE 4.3. Fully Developed Turbulent Flow Friction Factor Correlations for a $\boxed{\text{Rough}}$ Circular Duct

Investigators	Correlation		Remarks
von Kármán [6]	$\frac{1}{\sqrt{f}} = 3.36 - 1.763 \ln \frac{\epsilon}{a}$	COMPLETELY ROUGH	This explicit theoretical formula is applicable for $Re_\epsilon > 70$.
Nikuradse [34]	$\frac{1}{\sqrt{f}} = 3.48 - 1.737 \ln \frac{\epsilon}{a}$	COMPLETELY ROUGH	This experimentaly derived formula gives very nearly the same results as the foregoing formula, also for $Re_\epsilon > 70$.
Colebrook and White [65]	$\frac{1}{\sqrt{f}} = 3.48 - 1.7372 \ln\left(\frac{\epsilon}{a} + \frac{9.35}{Re\sqrt{f}}\right)$	ALL	This implicit formula is applicable for $5 \le Re_\epsilon \le 70$ spanning the transition, hydraulically smooth, and completely rough flow regimes.
Moody [36]	$f = 1.375 \times 10^{-3}\left[1 + 21.544\left(\frac{\epsilon}{a} + \frac{100}{Re}\right)^{1/3}\right]$	ALL	Shows a maximum deviation of −15.78% from the Colebrook-White equation for $4000 \le Re \le 10^8$ and $2 \times 10^{-8} \le \epsilon/a \le 0.1$.
Haaland [75]	$\frac{1}{\sqrt{f}} = 3.4735 - 1.5635 \ln\left[\left(\frac{\epsilon}{a}\right)^{1.11} + \frac{63.6350}{Re}\right]$	ALL	Shows a maximum deviation of +1.21% from the Colebrook-White equation for $4000 \le Re \le 10^8$ and $2 \times 10^{-8} \le \epsilon/a \le 0.1$.

USE $\boxed{4f}$ FROM THESE CORRELATIONS TO OBTAIN SAME f THAT IS IN MOODY DIAGRAM.

$$\frac{V^2}{2g}\left\{1+\left(\frac{L}{D}\right)4\cdot\left[3.4735-1.5635\ln\left[\left(2\frac{k_s}{D}\right)^{1.11}+63.635\frac{\nu}{DV}\right]\right]^{-2}\right\}-H=0$$

COMPUTER SOLUTION. USE THE HAALAND CORRELATION FOR THE FRICTION FACTOR, f.