Pressure Drop Calculations & Optimum Line Size Selection Using Explicit Emperical Equations

302 ft

Image shows approximate pipe length required, add extra 20% margin for piping turns & elevations

These are `python` libraries needed for unit conversion & mathematical functions

In [1]:

```
import handcalcs.render
from handcalcs.decorator import handcalc
from math import log, log10, sqrt, pi, exp
```

In [2]:

```
import forallpeople as si
si.environment('ukhan', top_level=True)
```

Research paper: [A review of non iterative friction factor correlations for the calculation of pressure drop in pipes (https://dergipark.org.tr/tr/download/article-file/40279)](https://dergipark.org.tr/tr/download/article-file/40279)

> Results gained from error analysis are briefly explained below. If the approximation formulas are scaled in the order of relative error, best results are obtained from the Goudar & Sonnad (2008) and Serghides (1984) correlations . The worst results are gained from the Altshul (1952) and Wood (1966) correlations. When a comparison is made according to the degree of the relative error, the Goudar & Sonnad (2008) correlation with an error percentage 10-9 % is very close to the result obtained from the Colebrook-White equation. Then the next best equation is achieved by the Serghides (1984) correlation with an error percentage of 10-4 % which can also be used practically. Because of the high precision of the selected correlations, the need for using the Colebrook-White iterative solution seems to be eliminated.

Table-1 Pipe Fittings Equivalent Lengths

Fitting	Types	(L/D)eq
90° Elbow Curved, Threaded	Standard Radius (R/D = 1)	30
	Long Radius (R/D = 1.5)	16
90° Elbow Curved, Flanged/Welded	Standard Radius (R/D = 1)	20
	Long Radius (R/D = 2)	17
	Long Radius (R/D = 4)	14
	Lon g Radius (R/D = 6)	12
90° Elbow Mitered	1 weld (90°)	60
	2 welds (45°)	15
	3 welds (30°)	8
45° Elbow Curved. Threaded	Standard Radius (R/D = 1)	16
	Long Radius (R/D = 1.5)	
45° Elbow Mitered	1 weld 45°	15
	2 welds 22.5°	6
180° Bend	threaded, close-return (R/D = 1)	50
	flanged (R/D = 1)	
	all types (R/D = 1.5)	
Tee Through-branch as an Elbow	threaded (r/D = 1)	60
	threaded (r/D = 1.5)	
	flanged (r/D = 1)	20
	stub-in branch	
Tee Run-through	threaded (r/D = 1)	20
	flanged (r/D = 1)	
	stub-i n branch	
Angle valve	45°, full line size, β = 1	55
	90° full line size, β = 1	150
Globe valve	standard, β = 1	340
Plug valve	branch flow	90
	straight through	18
	three-way (flow through)	30
Gate valve	standard, β = 1	8
Ball valve	standard, β = 1	3
Diaphragm	dam type	
Swing check valve	V_{min} = 35 [ρ (lbm/ft^^{3})]$^{-1/2}$	100
Lift check valve	V_{min} = 40 [ρ (lbm/ft^3)]$^{-1/2}$	600
Hose Coupling	Simple, Full Bore	5

Table-2 Absolute Roughness ξ

Material	Roughness (mm)
Drawn Tubing, Glass, Plastic	0.0015-0.01
Drawn Brass, Copper, Stainless Steel (New)	>0.0015-0.01
Flexible Rubber Tubing - Smooth	0.006-0.07
Flexible Rubber Tubing - Wire Reinforced	0.3-4
Stainless Steel	0.03
Wrought Iron (New)	0.045
Carbon Steel (New)	0.02-0.05
Carb on Steel (Slightly Corroded)	0.05-0.15
Carbon Steel (Moderately Corroded)	0.15-1
Carbon Steel (Badly Corroded)	1-3
Carbon Steel (Cement-lined)	1.5
Asphalted Cast Iron	0.1-1
Cast Iron (new)	0.25
Cast Iron (old, sandblasted)	1
Sheet Metal Ducts (with smooth joints)	0.02-0.1
Galvanized Iron	0.025-0.15
Wood Stave	0.18-0.91
Wood Stave, used	0.25-1
Smooth Cement	0.5
Concrete – Very Smooth	0.025-0.2
Concrete – Fine (Floated, Brushed)	0.2-0.8
Concrete – Rough, Form Marks	0.8-3
Riveted Steel	0.91-9.1
Water Mains with Tuberculations	1.2
Brickwork, Mature Foul Sewers	3

Source: [https://neutrium.net (https://neutrium.net/fluid-flow/pressure-loss-from-fittings-in-pipe-summary/)](https://neutrium.net/fluid-flow/pressure-loss-from-fittings-in-pipe-summary/)

In [3]:

```
%%render params 1
PipeL = (302*1.2) *ft.to(m)  #20% additional length
PipeID = 50 *mm  #Internal Dia
PP_xi = 0.01 *mm  #PolyPropylene Roughness
```

$\mathrm{PipeL} = 110.5\ \mathrm{m}\ \ (20\%\ \text{additional length})\qquad \mathrm{PipeID} = 50.0\ \mathrm{mm}\ \ (\text{Internal Dia})$

In [4]:

```
%%render params 1
flow_H2O = 5 *m3_h
rho_H2O = 988 *kg_m3.prefix('unity') # at 50°C
nu_H2O = 0.5465 *cP #Viscosity in centiPoise is equal to mPa.s
```

$\mathrm{flow}_{H2O} = 5.0\ \mathrm{m^3} \cdot \mathrm{h}^{-1} \qquad \rho_{H2O} = 988.0\ \mathrm{kg} \cdot \mathrm{m}^{-3}\ \ (\text{at } 50°\mathrm{C}) \qquad \nu_{H2O} = 546.5\ \mu\mathrm{l}$

Water physical properties: [https://wiki.anton-paar.com/en/water/ (https://wiki.anton-paar.com/en/water/)](https://wiki.anton-paar.com/en/water/)

In [5]:

```
%%render params 1
Elbows = 10  #90° Elbow Threaded Standard
Elbow_EqFactor = 30
Valves = 2 #Ball valve
Valve_EqFactor = 3  #Refer Table-1
```

$\mathrm{Elbows} = 10\ \ (90°\ \text{Elbow Threaded Standard}) \qquad \mathrm{Elbow}_{EqFactor} = 30 \qquad \mathrm{Va}$

$\mathrm{Valve}_{EqFactor} = 3\ \ (\text{Refer Table-1})$

In [6]:

```
%%render long
Sigma_PipeL = PipeL + (Elbows*Elbow_EqFactor*PipeID) + (Valves*Valve_EqFactor*PipeII
```

$$
\begin{aligned}
\Sigma_{PipeL} &= \mathrm{PipeL} + \left(\mathrm{Elbows} \cdot \mathrm{Elbow}_{EqFactor} \cdot \mathrm{PipeID}\right) + \left(\mathrm{Valves} \cdot \mathrm{Valve}_{EqFactor} \cdot \mathrm{PipeI}\right.\\
&= 110.460\ \mathrm{m} + (10 \cdot 30 \cdot 50.000\ \mathrm{mm}) + (2 \cdot 3 \cdot 50.000\ \mathrm{mm})\\
&= 125.760\ \mathrm{m}
\end{aligned}
$$

In [7]:

```
@handcalc(jupyter_display=True)
def reynolds(D, F, rho, nu):
    A = 0.25 * pi * D**2
    velocity = F / A  #Calculate velocity
    NRe = (D * velocity * rho) / nu #Calculate Reynold's number
    return velocity, NRe
```

In [8]:

```
velocity, NRe = reynolds(PipeID, flow_H2O, rho_H2O, nu_H2O)
```

$$A = 0.25 \cdot \pi \cdot (D)^{2} = 0.25 \cdot 3.142 \cdot (50.000\ \mathrm{mm})^{2}$$

$$\mathrm{velocity} = \frac{F}{A} = \frac{5.000\ \mathrm{m^3} \cdot \mathrm{h}^{-1}}{1963.495\ \mathrm{mm}^{2}}$$

$$\mathrm{NRe} = \frac{D \cdot \mathrm{velocity} \cdot \rho}{\nu} = \frac{50.000\ \mathrm{mm} \cdot 707.355\ \mathrm{mm} \cdot \mathrm{s}^{-1} \cdot 988.000\ \mathrm{kg} \cdot \mathrm{m}^{-3}}{546.500\ \mu\mathrm{Pa} \cdot \mathrm{s}}$$

In [9]:

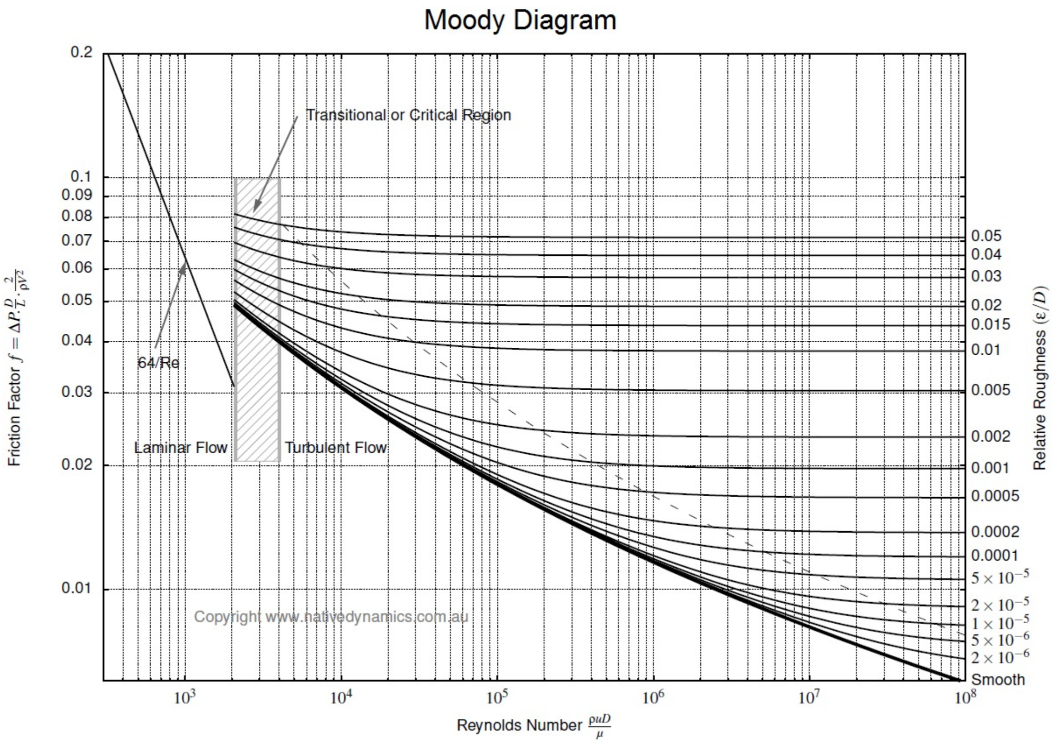
```
%%render 4
if NRe <= 2100: Flow = 'Laminar'
elif NRe <= 4000: Flow = 'Transient'
elif NRe > 4000: Flow = 'Turbulent'

PipeRR = PP_xi/PipeID #Pipe Relative Roughness
```

$$\text{Since, NRe} > 4000 \rightarrow (63940.2597 > 4000):$$

$$\text{Flow} = \text{Turbulent}$$

$$\text{PipeRR} = \frac{PP_{\xi}}{\text{PipeID}} = \frac{10.0000\ \mu\text{m}}{50.0000\ \text{mm}} = 0.0002 \quad \text{(Pipe Relative I}$$



Moody Friction Factor Figure

Method-1 Using Graph

Relative Roughness is 0.0002

Reynolds number is approximately $6.4 \cdot 10^4$

Friction factor f is approximately 0.022

In [10]:

```
@handcalc(jupyter_display=True)
def pressuredrop(f, Sigma_L, D, rho, velocity):
    Delta_p = f * (Sigma_L/D) * (rho*velocity**2)/2
    return Delta_p
```

In [11]:

```
Delta_p = pressuredrop(0.022,Sigma_PipeL, PipeID, rho_H2O, velocity)
```

$$
\begin{aligned}
\Delta_{p} &= f \cdot \left(\frac{\Sigma_{L}}{D} \right) \cdot \frac{\rho \cdot (\mathrm{velocity})^{2}}{2} \\
&= 0.022 \cdot \left(\frac{125.760\ \mathrm{m}}{50.000\ \mathrm{mm}} \right) \cdot \frac{988.000\ \mathrm{kg} \cdot \mathrm{m}^{-3} \cdot \left(707.355\ \mathrm{mm} \cdot \mathrm{s}^{-1}\right)^{2}}{2} \\
&= 13.677\ \mathrm{kPa}
\end{aligned}
$$

Method-2 Using Churchill Emperical Equation

In [12]:

```
@handcalc(jupyter_display=True, precision=4)
def churchill(NRe, D, xi):
    A = ( 2.457*log( 1 /( (7/NRe)**0.9 + 0.27*xi/D )) )**16
    B = (37530/NRe)**16
    f = 8 * ( (8/NRe)**12 + 1/(A+B)**1.5 )**(1/12)
    return f
```

In [13]:

```
f_churchill = churchill(NRe, PipeID, PP_xi)
```

$$
\begin{aligned}
A &= \left(2.457 \cdot \ln \left(\frac{1}{\left(\frac{7}{\mathrm{NRe}} \right)^{0.9} + 0.27 \cdot \frac{\xi}{D}} \right) \right)^{16} \\
&= \left(2.457 \cdot \ln \left(\frac{1}{\left(\frac{7}{63940.2597} \right)^{0.9} + 0.27 \cdot \frac{10.0000\ \mu\mathrm{m}}{50.0000\ \mathrm{mm}}} \right) \right)^{16} \\
&= 524038602297619775488.0000
\end{aligned}
$$

$$
B = \left(\frac{37530}{\mathrm{NRe}} \right)^{16} = \left(\frac{37530}{63940.2597} \right)^{16}
$$

$$
\begin{aligned}
f &= 8 \cdot \left(\left(\frac{8}{\mathrm{NRe}} \right)^{12} + \frac{1}{(A + B)^{1.5}} \right)^{\left(\frac{1}{12} \right)} \\
&= 8 \cdot \left(\left(\frac{8}{63940.2597} \right)^{12} + \frac{1}{(524038602297619775488.0000 + 0.0002)^{1.5}} \right)^{\left(\frac{1}{12} \right)} \\
&= 0.0206
\end{aligned}
$$

In [14]:

```
Delta_pChurchill = pressuredrop(f_churchill, Sigma_PipeL, PipeID, rho_H2O, velocity
```

$$
\begin{aligned}
\Delta_p &= f \cdot \left(\frac{\Sigma_L}{D} \right) \cdot \frac{\rho \cdot (\mathrm{velocity})^2}{2} \\
&= 0.021 \cdot \left(\frac{125.760\ \mathrm{m}}{50.000\ \mathrm{mm}} \right) \cdot \frac{988.000\ \mathrm{kg} \cdot \mathrm{m}^{-3} \cdot \left(707.355\ \mathrm{mm} \cdot \mathrm{s}^{-1}\right)^2}{2} \\
&= 12.786\ \mathrm{kPa}
\end{aligned}
$$

Method-3 Using Serghides Emperical Equation

In [15]:

```
@handcalc(jupyter_display=True, precision=4)
def serghide(NRe, D, xi):
    A = -2*log10( (xi/D)/3.7 + 12/NRe )
    B = -2*log10( (xi/D)/3.7 + 2.51*A/NRe )
    C = -2*log10( (xi/D)/3.7 + 2.51*B/NRe )
    f = ( A - ( (B-A)**2 )/(C - 2*B + A) )**(-2)
    return f
```

In [16]:

```
f_serghide = serghide(NRe, PipeID, PP_xi)
```

$$A = (-2) \cdot \log_{10}\left(\frac{\frac{\xi}{D}}{3.7} + \frac{12}{\mathrm{NRe}} \right) = (-2) \cdot \log_{10}\left(\frac{\frac{10.0000\ \mu\mathrm{m}}{50.0000\ \mathrm{mm}}}{3.7} + \frac{12}{63940.2597} \right)$$

$$\begin{aligned} B &= (-2) \cdot \log_{10}\left(\frac{\frac{\xi}{D}}{3.7} + 2.51 \cdot \frac{A}{\mathrm{NRe}} \right) \\ &= (-2) \cdot \log_{10}\left(\frac{\frac{10.0000\ \mu\mathrm{m}}{50.0000\ \mathrm{mm}}}{3.7} + 2.51 \cdot \frac{7.2333}{63940.2597} \right) \\ &= 6.9422 \end{aligned}$$

$$\begin{aligned} C &= (-2) \cdot \log_{10}\left(\frac{\frac{\xi}{D}}{3.7} + 2.51 \cdot \frac{B}{\mathrm{NRe}} \right) \\ &= (-2) \cdot \log_{10}\left(\frac{\frac{10.0000\ \mu\mathrm{m}}{50.0000\ \mathrm{mm}}}{3.7} + 2.51 \cdot \frac{6.9422}{63940.2597} \right) \\ &= 6.9720 \end{aligned}$$

$$f = \left(A - \frac{(B - A)^2}{C - 2 \cdot B + A} \right)^{(-2)} = \left(7.2333 - \frac{(6.9422 - 7.2333)^2}{6.9720 - 2 \cdot 6.9422 + 7.2333} \right)^{(-2)}$$

In [17]:

```
Delta_pSerghide = pressuredrop(f_serghide, Sigma_PipeL, PipeID, rho_H2O, velocity)
```

$$\begin{aligned} \Delta_p &= f \cdot \left(\frac{\Sigma_L}{D} \right) \cdot \frac{\rho \cdot (\mathrm{velocity})^2}{2} \\ &= 0.021 \cdot \left(\frac{125.760\ \mathrm{m}}{50.000\ \mathrm{mm}} \right) \cdot \frac{988.000\ \mathrm{kg} \cdot \mathrm{m}^{-3} \cdot \left(707.355\ \mathrm{mm} \cdot \mathrm{s}^{-1}\right)^2}{2} \\ &= 12.800\ \mathrm{kPa} \end{aligned}$$

Method-4 Goudar- Sonnad

In [18]:

```
@handcalc(jupyter_display=True, precision=4)
def gsonnad(NRe, D, xi):
    a = 2/log(10)
    b = (xi/D)/3.7
    d = log(10)/5.02 *NRe
    s = b*d + log(d)
    q = s**( s/(s+1) )
    g = b*d + log(d/q)
    zeta = q/g
    delta_LA = (g/(g+1))*zeta
    delta_CFA = delta_LA * ( 1 + (zeta/2)/( (g+1)**2 + (zeta/3)*(2*g-1) ) )
    f =  1/( a* ( log(d/q)+ delta_CFA ) )**2
    return f
```

In [19]:

```
f_gsonnad = gsonnad(NRe, PipeID, PP_xi)
```

$$a = \frac{2}{\ln(10)} = 0.86$$

$$b = \frac{\frac{\xi}{D}}{3.7} = \frac{\frac{10.0000\ \mu\mathrm{m}}{50.0000\ \mathrm{mm}}}{3.7} = 0.00$$

$$d = \frac{\ln(10)}{5.02} \cdot \mathrm{NRe} = \frac{\ln(10)}{5.02} \cdot 63940.2597 = 29328.26$$

$$s = b \cdot d + \ln(d) = 0.0001 \cdot 29328.2647 + \ln(29328.2647) = 11.87$$

$$q = (s)^{\left(\frac{s}{s+1}\right)} = (11.8716)^{\left(\frac{11.8716}{11.8716+1}\right)} = 9.79$$

$$g = b \cdot d + \ln\left(\frac{d}{q}\right) = 0.0001 \cdot 29328.2647 + \ln\left(\frac{29328.2647}{9.7956}\right) = 9.58$$

$$\zeta = \frac{q}{g} = \frac{9.7956}{9.5897} = 1.02$$

$$\delta_{LA} = \left(\frac{g}{g+1}\right) \cdot \zeta = \left(\frac{9.5897}{9.5897+1}\right) \cdot 1.0215 = 0.92$$

$$\begin{aligned} \delta_{CFA} &= \delta_{LA} \cdot \left(1 + \frac{\frac{\zeta}{2}}{(g+1)^2 + \left(\frac{\zeta}{3}\right) \cdot (2 \cdot g - 1)}\right) \\ &= 0.9250 \cdot \left(1 + \frac{\frac{1.0215}{2}}{(9.5897+1)^2 + \left(\frac{1.0215}{3}\right) \cdot (2 \cdot 9.5897 - 1)}\right) \\ &= 0.9290 \end{aligned}$$

$$\begin{aligned} f &= \frac{1}{\left(a \cdot \left(\ln\left(\frac{d}{q}\right) + \delta_{CFA}\right)\right)^2} \\ &= \frac{1}{\left(0.8686 \cdot \left(\ln\left(\frac{29328.2647}{9.7956}\right) + 0.9290\right)\right)^2} \\ &= 0.0166 \end{aligned}$$

In [20]:

```
Delta_pGsonnad = pressuredrop(f_gsonnad, Sigma_PipeL, PipeID, rho_H2O, velocity)
```

$$\begin{aligned}
\Delta_p &= f \cdot \left(\frac{\Sigma_L}{D} \right) \cdot \frac{\rho \cdot (\text{velocity})^2}{2} \\
&= 0.017 \cdot \left(\frac{125.760\ \mathrm{m}}{50.000\ \mathrm{mm}} \right) \cdot \frac{988.000\ \mathrm{kg} \cdot \mathrm{m}^{-3} \cdot \left(707.355\ \mathrm{mm} \cdot \mathrm{s}^{-1}\right)^2}{2} \\
&= 10.326\ \mathrm{kPa}
\end{aligned}$$

Summary

In [21]:

```
from IPython.display import HTML, display

def display_table(data):
    html = "<table>"
    for row in data:
        html += "<tr>"
        for field in row:
            html += "<td><h4>%s</h4></td>"%(field)
        html += "</tr>"
    html += "</table>"
    display(HTML(html))

data = [['Emperical Relationship','Friction Factor','Pressure Drop'],
        ['Churchill', round(f_churchill,4), Delta_pChurchill],
        ['Serghide', round(f_serghide,4), Delta_pSerghide],
        ['Goudar-Sonnad', round(f_gsonnad,4), Delta_pGsonnad]]
display_table(data)
```

Emperical Relationship	Friction Factor	Pressure Drop
Churchill	0.0206	12.786 kPa
Serghide	0.0206	12.800 kPa
Goudar-Sonnad	0.0166	10.326 kPa

In [22]:

```
%reload_ext version_information
%version_information handcalcs, forallpeople
```

Out[22]:

Software	Version
Python	3.9.18 64bit [Clang 14.0.7 (https://android.googlesource.com/toolchain/llvm-project 4c603efb]
IPython	7.34.0
OS	Linux 4.19.113 27114284 aarch64 with libc
handcalcs	1.6.5
forallpeople	2.6.7
	Sat Jan 20 00:41:30 2024 +03