Friction Loss (F) & MEB

\[ \frac{1}{2 \times (V_2^2 - V_1^2)} + g(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + (\sum F + W_s) = 0 \]

\[ \sum F \]

\[ \sum F_{\text{pipe}} \]

Friction loss in circular pipe (straight) [LIQUID]

(1) Friction loss in pipe

1st Pipes: Circular

Commercial steel, plastic, copper etc. material

App 5 - the properties of commercial steel

\[ \Delta r \rightarrow \text{thickness of pipe} \]

Sch 40 & Sch 80

\[ \Delta r_{40} < \Delta r_{80} \]

\[ \text{OD}_{40} = \text{OD}_{80} \]

(for some coupling/fitting)
Resistivity of #80 > Resistivity of #40
to pressure
due to big $\Delta r$ (thicker)

Friction in pipe (straight)

$$F_f, \text{pipe} = \frac{\Delta \rho_f}{\rho_f} \Rightarrow \frac{N \cdot m}{k g} \text{ or } \frac{f t \cdot l b}{l b}$$

$$\Delta \rho_f = \rho_f - \rho_2$$

$\Delta P = \text{Pressure diff} = \text{Pressure drop}$

$P_1 > P_2$

$L$: length of pipe $(L_2 - L_1)$

$D$: inside diameter of pipe

$S$: density of fluid $(l b / f t^2)$

$$F_f = \frac{\Delta \rho_f}{\rho_f}$$

From Hagen-Poiseuille Eq:

$$\bar{v} = \bar{v}_m = \frac{(P_0 - P_L)}{32 \mu L} \cdot D^2$$

$$\Delta \rho_f = (P_0 - P_L) \text{ or } (P_1 - P_2) = \frac{32 \mu \bar{v} \cdot (L_2 - L_1)}{D^2}$$

(British)

$$\Delta \rho_f = \frac{32 \mu \bar{v} \cdot (L_2 - L_1)}{D^2 \cdot \rho_f}$$

(ST)
If fluid is:

liquid (!)

\( P \): constant

Newtonian fluid, or Non-Newtonian fluid (in pipe) same

\[
F_f = (p_1 - p_2)_f = \frac{32 \cdot \mu \cdot \bar{V} \cdot (L_2 - L_1)}{\frac{1}{D^2}} = \frac{32 \cdot \mu \cdot \bar{V} \cdot (L_2 - L_1)}{\frac{1}{D^2}}
\]

This is perfectly smooth inside surface pipe wall. But, it is not possible inside of wall is rough. So, there is Fanning friction \((f)\).
\( f \): Friction factor in pipe.

\( f \): Means that DRAG FORCE (as shear force) per wetted surface unit area, divided by density and velocity head \( \left( \frac{\bar{v}}{2} \right) \).

Drage force (shear force) = shear stress \( \times \) Across.

\[ \text{Across} = 2\pi R^2 \]

Wetted inside wall surface

Perimeter

\[ 2\pi R \]

\[ \text{Area} = 2\pi R \cdot L \]

So:

\[ f = \frac{\text{Drag force, per wetted area}}{\frac{S}{L} \times \frac{\bar{v}}{2}} \]
\[ F = \frac{\Delta P}{A} \text{ or } 2\bar{A} \]

\[ \frac{\Delta P}{A} \text{ Cross} \]

\[ 2\pi R \frac{\Delta L}{\text{wetted}} \]

\[ P = \frac{U^2}{2} \]

Re-arrange:

\[ \Delta p_f = 4 \cdot f \cdot P \cdot \frac{\Delta L}{D} = \frac{U^2}{2} \quad (\text{SI}) \]

\[ \Delta p_f = 4 \cdot f \cdot P \cdot \frac{\Delta L}{D} = \frac{U^2}{2g_c} \quad (\text{British}) \]

Pressure drop in pipe with friction factor:

So, what is \( \Delta F_f \) in pipe?

\[ \Delta F_f = \frac{\Delta p_{\text{pipe}}}{P} \]

\[ \Delta F_f = 4 \cdot f \cdot \frac{\Delta L}{D} = \frac{U^2}{2} \quad (\text{SI}) \frac{1}{\text{kg}} \text{ or } \frac{\text{N.m}}{\text{kg}} \]

\[ \Delta F_f = 4 \cdot f \cdot \frac{\Delta L}{D} = \frac{U^2}{2g_c} \quad (\text{British}) \frac{\text{ft. lb}}{\text{lbm}} \text{ or } \frac{\text{Btu}}{\text{lbm}} \]
\[ f = \frac{16}{N_R e} \]

* if laminar flow (L.F.)

* if turbulent flow (T.F.)

Use Moody's chart

\[ f = f(N_R e, \text{roughness of pipe surface}) \]
Pipe & Turbulent

Pressure drop and friction for turbulent flow in a pipe

In terms of calculated using formula:

\[ \Delta P_f = \frac{4f}{D} \cdot \frac{AL}{2} \cdot \frac{U^2}{2} \quad (SI) \]

Then:

\[ F_p = \frac{\Delta P_f}{f} = 4f \cdot \frac{AL}{D} \cdot \frac{U^2}{2} \quad (SI) \]

Moody's Chart (diagram)

Roughness (e) → Figure 2.10-3 (log chart)

f vs. NRe

Log graph.

Then use formula for \( \Delta P_f \) or \( F_p \):

Relative roughness:

Relative roughness (E/D) in Moody's diagram:

Diameter of pipe (E/D) → e

The most common commercial steel (E=4.6105 m) NRe

\( E = 1.5 \times 10^{-4} \) ft

Then:

\[ \Delta P_f = 4f \cdot \frac{AL}{D} \cdot \frac{U^2}{2} \quad (SI) \]

\[ F_p = \frac{\Delta P_f}{f} = 4f \cdot \frac{AL}{D} \cdot \frac{U^2}{2} \quad (SI) \]

As a summary:

\( F_p \) & \( \Delta P_f \) same for laminar and turbulent

\( f \): laminar \( f = \frac{16}{NRe} \)

\( f \): turbulent \( f \) - from Figure 2.10-3
**Figure 2.10-3.** Friction factors for fluids inside pipes. [Based on L. F. Moody, Trans. A.S.M.E., 66, 671, (1944); Mech. Eng. 69, 1005 (1947). With permission.]
friction loss in noncircular conduits:

\[ F_f = \frac{\Delta P_f}{g} = 4 \frac{\Delta L \cdot u^2}{D^2} \quad \text{like circular pipe} \]

\[ D = 4 \tau_4 = \frac{\text{cross-sectional area of channel}}{\text{wetted perimeter of channel}} \]

For circular:

\[ D = \frac{2\pi \tau}{\pi \tau/4} \]

For rectangular duct:

\[ D = \frac{a \cdot b}{2(a+b)} \]

Open and partly filled duct:

\[ D = \frac{b+y}{b+2y} \]

For wide, shallow stream of depth \( y \): \[ D = 4 \cdot y \]
Ex 2.10-3
- Horizontal pipe
- \( V = 4.57 \text{ m/s} \)
- Com: steel
- Sch 40, 2-in nominal diameter
- \( \mu = 4.46 \text{ cp} \)
- \( \rho = 801 \text{ kg/m}^3 \)
- \( F_f = \frac{1}{kg} \) ? for a 36.6 m section of pipe.

Sol'n:
- from App A.5 [Sch:40]/2 in nominal
- \( D = 0.0525 \text{ m} \)
- \( \Delta L = 36.6 \text{ m} \)
- \( \mu = (4.46 \text{ cp})(10^{-3}) = 4.46 \times 10^{-3} \text{ kg/m} \cdot \text{s} \)

\[
N_{pe} = \frac{D \cdot V \cdot \rho}{\mu} = \frac{0.0525 \times 4.57 \times 801}{4.46 \times 10^{-3}} = 4.310 \times 10^4
\]

be careful

\( > 4100 \) (Turbulent)

\( E = 4.610^5 \text{ M} \)

\[
\frac{E}{D} = \frac{4.610^5}{0.0525} \approx 880000 \approx \text{From Figure 2.10-3} \]

\( N_{pe} = 4.310 \times 10^4 \)

\begin{align*}
F_f &= \frac{4 \cdot \Delta L \cdot V^2}{D} = 4 \times 0.006 \times 36.6 \times (4.57)^2 \quad \text{or} \quad 58.5 \frac{\text{ft-lbf}}{\text{lbm}}
\end{align*}

moody's diagram

\( P = 0.006 \)
Ex 2.10-1 and 2.10-2

Capillary tube

\[ \Delta p_c = 0.0655 \text{ m (density: 996) head.} \]

\[ Q = ? \quad (\text{m}^3/\text{s}) \]

\[ \Delta p_f = ? \quad \text{(use fanning friction factor)} \]

---

**Solution**

- Assume (capillary) \( \rightarrow \) laminar

- Head conversion:

\[ \Delta p_f = h_p g \Delta \text{h} = (0.0655 \text{ m}) \times (996 \text{ kg/m}^3)(9.8 \text{ m/s}^2) \]

\[ \Rightarrow 640 \text{ kg m/s}^2 \cdot \text{m} \]

\[ \Rightarrow 640 \text{ N/m}^2 \]

From Hagen-Poiseuille eq. (HPF)

\[ \Delta p_f: \quad \frac{32 \mu \bar{u} (L_2 - L_1)}{D^2} \quad \text{put:} \]

\[ 640 = \frac{(32)(1 \times 10^{-3})^7}{D^2} (\bar{u}, 0.317) \]

\[ \Rightarrow \bar{u} = 0.275 \text{ m/s} \]

\[ \theta: \quad \bar{u} = \bar{u}_t \cdot \pi \frac{D^2}{4} = 0.275 \cdot \pi \frac{(0.317)^2}{4} = 1.066 \times 10^6 \text{ m/s}^2 \]

To check our assumption: make \( \text{Re} \) calculation.

\[ \text{Re} = \frac{D \bar{u} \rho}{\mu} = \frac{(2.22 \times 10^{-3}) \cdot 0.275 \cdot 875}{1.13 \times 10^{-3}} = 473 \]

\[ \text{LQRAY} \]

Assumption is true.
\[ N_{Re} = 473 \]

\[ f = \frac{16}{N_{Re}} = \frac{16}{473} = 0.0338 \quad \text{dimensionless} \]

\[ \Delta P_f = 4f \frac{\Delta L}{D} \frac{w^2}{2} = \frac{4 \times (0.0338) \times (875) \times (0.375) \times (0.275)^2}{(22.2 \times 10^{-3}) \times 2} = 640 \text{ N/m}^2 \]
Ex 2.10.4: (Trial & Error)

- Water
- T = 4.4 °C
- Horizontal pipe
- Commercial steel pipe
- L = 305 m
- \( \Theta = 150 \text{ gal/min} \)
- Head of water = 6.1 m to overcome \( F_p \)
- \( D = ? \)

**Solution:**

- App. A.2: \( \rho = 1000 \text{ kg/m}^3 \) at 4.4 °C, water
  \[ \mu = 1.55 \text{ cp} \times 10^{-3} = 1.55 \times 10^{-3} \text{ kg/m.s} \]

- Due to overcome friction:
  \[ F_p = \text{head} \times g \Rightarrow (6.1 \text{ m}) \times g = 6.1 \times 9.8 = 59.82 \text{ J/kg} \]

- \( \Delta p = h \cdot g \)

- \( \frac{F_p}{\rho} = h \cdot g \)

- \( \Theta = \frac{150 \text{ gal}}{\text{min}} \times \frac{1 \text{ ft}^3}{7.48 \text{ gal}} \times \frac{1 \text{ min}}{60 \text{ s}} \times \frac{0.0283167 \text{ m}^3}{1 \text{ ft}^3} = 9.46 \times 10^{-3} \text{ m}^3/\text{s} \)

- \( A = \pi \frac{D^2}{4} \Rightarrow (D = ?) \)

- \( \bar{v} = \frac{\Theta}{A} \Rightarrow \frac{9.46 \times 10^{-3} \text{ m}^3/\text{s}}{\pi \frac{D^2}{4}} \Rightarrow \frac{0.01204 \text{ m/s}}{D^2} \)

Now trial - error.
D, \nu \rightarrow N_{re} \text{ and } f.

**Trial 1:**

Let \( D = 0.089 \) m

\[
N_{re} = \frac{D \cdot \nu \cdot \rho}{\mu} = 0.089 \left( \frac{0.01204 \times 1000}{0.089^2 \times 1.55 \times 10^{-3}} \right) = 8.73 \times 10^4
\]

Now, Fig. 2.10-3 for Cor. steel, \( E = 4.6 \times 10^5 \) m

\[
\frac{E}{D} = \frac{4.6 \times 10^5}{0.089} = 0.0052
\]

\[
\downarrow \quad \text{N}_{re} = 8.73 \times 10^4
\]

\[
\downarrow \quad \text{From figure}
\]

\[
\downarrow \quad f = 0.0054
\]

So,

\[
F \frac{P}{D} = 4f \cdot \frac{AL}{D} \cdot \frac{u^2}{2} = 4 \times 0.0054 \times \frac{805}{D} \times \frac{(0.01204)^2}{2 \times 1.4}\]

\[
D \approx 0.0945 \text{ m} \quad \text{not equal.} \]

Assumed \( D = 0.089 \) m

**Trial 2:** Let \( D = 0.0945 \) m.

Use same procedure

\[
N_{re} = 8.22 \times 10^4
\]

\[
\frac{E}{D} = 0.00049
\]

\[
f = 0.0052
\]

\[
D = 0.0945 \text{ m calculated}
\]

So, same

\[
D = 0.0945 \text{ m}
\]
F) Friction losses in expansion, contraction and pipe fittings [fanning friction factor, elbow, tee, valve, etc.]

- in pipe (no fraction) \( F_f \) calculate \( \rightarrow F_g \) (previous calculations)
  - if \( f \) direction [yellow]
  - diameter (enlargement/contraction) \( \rightarrow \) friction occurs due to vortex

2. Friction loss due to sudden enlargement (friction losses):
   (Remember previous example).

   Enlargements in piping systems:

   ![Diagram of piping systems with sudden and non-sudden enlargements]

   - Sudden:
     - Tank
     - Water level (!)
     - Sudden
   - Not sudden:
     - Tank
     - No eddies
     - Water level

   X (reduction gradually, it's also seen for sudden!)

   X (no eddies)

   X (no eddies)
Friction loss = \( \frac{(u_1 - u_2)^2}{2\alpha} = \left(1 - \frac{A_1}{A_2}\right)^2 \frac{u_1^2}{2\alpha} \) (5f)

\( \alpha = 1 \quad \text{Turb.} \)

\( \alpha = 0.5 \quad \text{Lam.} \)

\( A_1, A_2 \quad \text{cross-sectional area.} \)

\( \bar{u} \quad \text{average vel.} \)

\( K_{ex} \quad \text{expansion coeff.} \)

\( K_{ex} = \left(1 - \frac{A_1}{A_2}\right)^2 \)

Note: If there is a tab \( A_2 \gg A_1 \quad \text{so} \quad \frac{w_2}{A_2} \ll \frac{w_1}{A_1} \quad \Rightarrow \quad A_2 \ll A_1 \) \( \frac{A_1}{A_2} \)

For Eng. system divided by \( (g_c) \).

\[ h = \frac{ft \cdot \text{lbm}}{\text{lbm}} \]

\[ F_{ex} = \left(1 - \frac{A_1}{A_2}\right) \frac{u_1^2}{2\alpha \cdot g_c} \quad \text{(Brodahl)} \]
Friction loss due to sudden contraction losses:

\[ h_c = 0.55 \left(1 - \frac{A_2}{A_1}\right) \frac{u_2^2}{2x} = K_c \frac{u_2^2}{2x} \]

Note: In tank + pipe

\[ A_1 \gg A_2 \quad \Rightarrow \quad \text{So } A_2 = 0 \text{ (for calculation)} \]

\[ u_1 \ll u_2 \quad \Rightarrow \quad \text{So } u_1 \approx 0. \text{ (we can take)} \]

KC: contraction-loss coeff. \[ KC = 0.55 \left(1 - \frac{A_2}{A_1}\right) \]

\( x; \ \text{air & liquid} \)

For Eng: Sc = divided part
Friction losses due to fittings (elbows, flowmeters, valve, coupling etc.)

Loses in fittings and valves
(elbow, flowmeters, valve, coupling etc.)

Elbows:

Bend:

Coupling:

Tee:

Valves:

gate

globe

bell

wheel

Flexible pipe

Check-value (safety-value)

High press.

Depressurization cooker.

Valve

Check-value

One-way flow

Crosses
Method 1: $h_f = \frac{\alpha}{\pi \nu} \left( \frac{\rho}{\rho_c} \right) \left( \frac{\bar{v}_1}{2g_c} \right)$

$K_f$ from Table 2.10.1 (First numerical value)

(Turbulent flow)

Table 2.10.2

(Laminar flow)

Method 2: $\frac{Le}{D}$ (equivalent length)

Equivalent length

we can use: "Equivalent length"

Table 2.10.1 (last column value)

$\frac{Le}{D}$ instead of $K_f$ or $h_f$ → all frictional losses written as equivalent length

Straight pipe in pipe diameter.

Find $Le$

Then, use in pipe formula:

$F_p = \frac{4}{D} \left( \frac{AL}{D} \right) \frac{u_2}{2}$

$Le$ written as equivalent loss conversion to straight pipe $L_e$.

Solve all example using $Le/L_e$
due to eddies formed by the jet expanding in the enlarged section. This friction loss can be calculated by the following for turbulent flow in both sections. This Eq. (2.8-36) was derived in Example 2.8-4.

\[
h_{ex} = \frac{(v_1 - v_2)^2}{2\alpha} = \left[1 - \frac{A_1}{A_2}\right]^2 \frac{v_1^2}{2\alpha} = K_{ex} \frac{v_1^2}{2\alpha} \frac{J}{\text{kg}} \tag{2.10-15}
\]

where \( h_{ex} \) is the friction loss in J/kg, \( K_{ex} \) is the expansion-loss coefficient and \( \alpha = (1 - A_1/A_2)^2 \), \( v_1 \) is the upstream velocity in the smaller area in m/s, \( v_2 \) is the downstream velocity, and \( \alpha = 1.0 \). If the flow is laminar in both sections, the factor \( \alpha \) in the equation becomes 1/2. For English units the right-hand side of Eq. (2.10-15) is divided by \( g_c \). Also, \( h = \text{ft} \cdot \text{lb}_{f}-\text{in} \).

2. Sudden contraction losses. When the cross section of the pipe is suddenly reduced, the stream cannot follow around the sharp corner, and additional frictional losses due to eddies occur. For turbulent flow, this is given by

\[
h_c = 0.55 \left(1 - \frac{A_2}{A_1}\right) \frac{v_2^2}{2\alpha} = K_c \frac{v_2^2}{2\alpha} \frac{J}{\text{kg}} \tag{2.10-16}
\]

where \( h_c \) is the friction loss, \( \alpha = 1.0 \) for turbulent flow, \( v_2 \) is the average velocity in the smaller or downstream section, and \( K_c \) is the contraction-loss coefficient (P1) and approximately equals 0.55 \((1 - A_2/A_1)\). For laminar flow, the same equation can be used with \( \alpha = \frac{1}{2} \)(S2). For English units the right side is divided by \( g_c \).

<table>
<thead>
<tr>
<th>Type of Fitting or Valve</th>
<th>Frictional Loss, Number of Velocity Heads, ( K_f )</th>
<th>Frictional Loss, Equivalent Length of Straight Pipe in Pipe Diameters, ( L/D )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow, 45°</td>
<td>0.35</td>
<td>17</td>
</tr>
<tr>
<td>Elbow, 90°</td>
<td>0.75</td>
<td>35</td>
</tr>
<tr>
<td>Tee</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>Return bend</td>
<td>1.5</td>
<td>75</td>
</tr>
<tr>
<td>Coupling</td>
<td>0.04</td>
<td>2</td>
</tr>
<tr>
<td>Union</td>
<td>0.04</td>
<td>2</td>
</tr>
<tr>
<td>Gate valve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide open</td>
<td>0.17</td>
<td>9</td>
</tr>
<tr>
<td>Half open</td>
<td>4.5</td>
<td>225</td>
</tr>
<tr>
<td>Globe valve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide open</td>
<td>6.0</td>
<td>300</td>
</tr>
<tr>
<td>Half open</td>
<td>9.5</td>
<td>475</td>
</tr>
<tr>
<td>Angle valve, wide open</td>
<td>2.0</td>
<td>100</td>
</tr>
<tr>
<td>Check valve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball</td>
<td>7.0</td>
<td>3500</td>
</tr>
<tr>
<td>Swing</td>
<td>2.0</td>
<td>100</td>
</tr>
<tr>
<td>Water meter, disk</td>
<td>7.0</td>
<td>350</td>
</tr>
</tbody>
</table>

3. Losses in fittings and valves. Pipe fittings and valves also disturb the normal flow lines in a pipe and cause additional friction losses. In a short pipe with many fittings, the friction loss from these fittings could be greater than in the straight pipe. The friction loss for fittings and valves is given by the following equation:

\[ h_f = K_f \frac{v_1^2}{2} \]  

(2.10-17)

where \( K_f \) is the loss factor for the fitting or valve and \( v_1 \) is the average velocity in the pipe leading to the fitting. Experimental values for \( K_f \) are given in Table 2.10-1 for turbulent flow (P1) and in Table 2.10-2 for laminar flow.

As an alternative method, some texts and references (B1) give data for losses in fittings as an equivalent pipe length in pipe diameters. These data, also given in Table 2.10-1, are presented as \( L_e/D \), where \( L_e \) is the equivalent length of straight pipe in m having the same frictional loss as the fitting, and \( D \) is the inside pipe diameter in m. The \( K \) values in Eqs. (2.10-15) and (2.10-16) can be converted to \( L_e/D \) values by multiplying the \( K \) by 50 (P1). The \( L_e \) values for the fittings are simply added to the length of the straight pipe to get the total length of equivalent straight pipe to use in Eq. (2.10-6).

4. Frictional losses in mechanical-energy-balance equation. The frictional losses from the friction in the straight pipe (Fanning friction), enlargement losses, contraction losses, and losses in fittings and valves are all incorporated in the \( \sum F \) term of Eq. (2.7-28) for the mechanical-energy balance, so that

\[ \sum F = 4f \frac{\Delta L}{D} \frac{v^2}{2} + K_{vt} \frac{v_1^2}{2} + K_c \frac{v_2^2}{2} + K_f \frac{v_1^2}{2} \]  

(2.10-18)

If all the velocities, \( v \), \( v_1 \), and \( v_2 \), are the same, then factoring, Eq. (2.10-18) becomes, for this special case,

\[ \sum F = \left( 4f \frac{\Delta L}{D} + K_{vt} + K_c + K_f \right) \frac{v^2}{2} \]  

(2.10-19)

The use of the mechanical-energy-balance equation (2.7-28) along with Eq. (2.10-18) will be shown in the following examples.

**EXAMPLE 2.10-6. Friction Losses and Mechanical-Energy Balance**

An elevated storage tank contains water at 82.2°C as shown in Fig. 2.10-4. It is desired to have a discharge rate at point 2 of 0.223 ft³/s. What must be the height \( H \) in ft of the surface of the water in the tank relative to the

<table>
<thead>
<tr>
<th>Type of Fitting or Valve</th>
<th>Frictional Loss, Number of Velocity Heads, ( K_f )</th>
<th>Reynolds Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Elbow, 90°</td>
<td>17</td>
<td>7</td>
</tr>
<tr>
<td>Tee</td>
<td>9</td>
<td>4.8</td>
</tr>
<tr>
<td>Globe valve</td>
<td>28</td>
<td>22</td>
</tr>
<tr>
<td>Check valve, swing</td>
<td>55</td>
<td>17</td>
</tr>
</tbody>
</table>

Chap. 2 Principles of Momentum Transfer and Overall Balances
Additional frictional loss for equipment:

If in system, then is an equipment:
- filter
- heat exchanger
- separator

→ pump should pass fluid through this equipment.

\[
\frac{\Delta P_f}{\rho g} = \frac{\text{Pressure difference (drop)}}{\text{Density of liquid}}
\]

\[
\frac{\Delta P}{\rho g} \quad \text{also gives energy requirement to pass through equipment}
\]
Summary:
Frictional losses in MEB: \( \sum F \) all

So, \( \sum F \) in MEB means that = Friction loss from:
- Straight pipe
- Construction
- Straight pipe
- Fitting/valve

\[ \sum F_p = F_p + F_e + F_{cont} + F_{fitting} + F_{equipment} \]

\[ \sum F = 4 \frac{F_p}{D} \frac{\Delta L}{2} + K_e \frac{\bar{u}_1^2}{2a} + K_c \frac{\bar{u}_2^2}{2a} + K_f \frac{D}{2} + \frac{F_{equipment}}{\Delta P_S} \]

\( \bar{u}_1 = \bar{u}_2 \)

\[ \sum F = \left( 4 \frac{F_p}{D} \frac{\Delta L}{2} + K_e + K_c + K_f \right) \frac{\bar{u}^2}{2} + \frac{F_{equipment}}{\Delta P_S} \]

\[ \frac{1}{2} \Delta u^2 + \frac{1}{2} \Delta z + \frac{\Delta P}{S} + \sum F + W_S = 0 \]