**Hydraulics**

- Hydraulics is the branch of sciences that deals with practical applications of water and other fluids. It includes **hydrostatics**, which deals with fluids at rest and **hydrodynamics**, which addresses forces exerted by or upon fluids in motion.

**Water**

- Almost a universal solvent
- Exists on earth in all three phases: liquid, gas, and solid
- Liquid density (62.5 lb/ft³ or 1 g/cm³) that changes very little with temperature
- Most dense at 38.4°F (4°C).

**Energy**

- Energy is the capacity to do work. Three forms of energy must be considered regarding the hydraulics of irrigation systems:
  - pressure energy,
  - kinetic energy, and
  - potential energy.

**Pressure Energy**

- Fluids must be contained to possess significant pressure energy.
  \[ h_p = \frac{p}{\rho g} = \frac{p}{g} \]
- Water contained in irrigation pipes can have a relatively large amount of pressure energy, while energy in water in open channels is limited to the depth of water in this channel.

**Pressure Energy**

- Usually, pressure is expressed as force per unit area. The units of pressure in the U.S Customary units are pound per square inch (psi) or lb/ft², while in SI system they are expressed in Pascals (Pa=N/m²), kilo-Pascals (kPa), bars or atmospheres (atm). The most common unit of pressure in the US is psi.
Pressure Energy
- For water in the pressurized pipe, the equivalent depth is the height to which water would rise in a stand pipe due to the pressure in the system. This height is called pressure head which is the height of a column of water that exerts a given pressure and is expressed in units of length (ft or m).

\[ p = \frac{F}{A} \]

\[ p = 62.4 \text{ lbs/sq ft} \]
\[ p = 0.433 \text{ psi} \]
\[ 1\text{ ft water} = 0.433 \text{ psi} \]

A column of water with the height of 1 ft will exert the pressure of 0.433 psi and pressure of 1 psi will raise a column of water 2.31 ft high.
- 1 ft H₂O = 0.433 psi
- 1 psi = 2.31 ft H₂O

Pressure Energy
- The static pressure exerted by the column of water is independent of the size, shape, and length of the vessel or pipeline.

Atmospheric Pressure
- Draw a vacuum
- Vapor Pressure
- 1 atmosphere of pressure
- 14 psi or 101.3 kPa

1 atmosphere of pressure
Potential Energy

- In an irrigation system the elevation head is a measure of the potential energy in the system. Elevation head is measured in units of length (ft or m). This can be directly compared to the pressure head which can be expressed in the length units. The elevation head can be converted also to pressure units.

Kinetic Energy

- The kinetic energy in an irrigation system is expressed as velocity head.

- It is a measure of the energy required to produce a certain velocity in a fluid.

Kinetic Energy

\[ h_v = \frac{v^2}{2g} \]

where:

- \( h_v \) = velocity head,
- \( v \) = velocity,
- \( g \) = acceleration due to gravity, 32.2 ft/s\(^2\) or 9.81 m/s\(^2\).

- Kinetic energy is expressed in terms of the velocity head.

- The velocity head is typically relatively small in comparison to pressure and elevation heads for most pressurized irrigation systems, though is of more substantial importance in open channel irrigation and drainage systems.
Kinetic Energy

- Note that the expression \( \frac{v^2}{2g} \) has units of length which are consistent with units of pressure head and elevation. This is why the kinetic energy of the fluid is often referred to as velocity head.

\[
h_{\text{sys}} = h_p + h_v + h_e = y + \frac{p}{\gamma_v} + \frac{v^2}{2g}
\]

where:
- \( h_p \) = pressure head,
- \( h_v \) = velocity head,
- \( h_e \) = elevation head, and
- \( h_{\text{sys}} \) = system head.

System Head

- At any point the sum of the elevation, pressure and velocity heads represents the system head at that point.

- The system head graphed relative to the length of the system represents the energy grade line, and indicates the potential that allows fluid to flow. The sum of the pressure and elevation heads is commonly referred to as the hydraulic grade line.

The valve is closed at point E. Relative to point E, what is the system head at points A, B, C, D and E?

- 170 ft.

Fundamental Flow Equation

- Simply put the fundamental flow equation states that the average flow rate exiting a control boundary of know cross-sectional area is equal to average velocity of the fluid normal to that cross-sectional area times that area.
**Fundamental Flow Equation**

\[ Q = A v \]

where:
- \( A \) = cross-sectional area of flow,
- \( v \) = average velocity, and
- \( Q \) = flow rate.

**Continuity Equation**

\[ Q_{in} = Q_{out} + \frac{\Delta S}{\Delta t} \]

where:
- \( Q_{in} \) = inflow rate,
- \( Q_{out} \) = outflow rate, and
- \( \Delta S / \Delta t \) = change in storage rate.

**Continuity Equation**

\[ v_{in} A_{in} = v_{out} A_{out} \]

**Example Calculations**

- \( A_1 = 6 \text{ sq in} \)
  - \( v_1 = 2.5 \text{ fps} \)
  - \( h_{sys} = h_p + h_v + h_e \)
- \( A_2 = 3 \text{ sq in} \)
  - \( v_2 = 5 \text{ fps} \)
- \( A_3 = 6 \text{ sq in} \)
  - \( v_3 = 1.7 \text{ fps} \)
  - \( h_{sys} = 22.8 \text{ ft} \)
- \( A_4 = 3 \text{ sq in} \)
  - \( v_4 = 5 \text{ fps} \)
  - \( h_{sys} = 22.8 \text{ ft} \)
Modified Bernoulli Equation

- The Bernoulli equation was modified with a lump loss parameter to account for the differences between the measured system head as water flow from one point to another.

\[ h_{sys1} + h_{p1} + h_{v1} - h_{loss1} = h_{sys2} + h_{p2} + h_{v2} \]

where:

- \( h_{sys1} \) = upstream system head,
- \( h_{sys2} \) = downstream system head,
- \( h_{loss1-2} \) = total friction losses.

Modified Bernoulli Equation

- Total head losses the sum of the loss due to friction along the length of the conduit plus the friction due to all the minor elements along the length of the conduit.

Friction Losses

\[ h_{loss} = h_f - \sum h_m \]

where:

- \( h_{loss} \) = total friction losses,
- \( h_f \) = pipe length friction loss,
- \( \Sigma h_m \) = sum of all minor losses.

Hazen-Williams Formula

\[ h_f = 10.52 \left( \frac{Q}{C} \right)^{1.852} d^{-4.867} l \]

where:

- \( h_f \) = pipe length friction loss, ft,
- \( C \) = Hazen-Williams coefficient,
- \( d \) = diameter, in,
- \( l \) = pipe length, ft, and
- \( Q \) = flow rate, gpm.
### Minor Losses

\[ h_m = k h_i = k \frac{v^2}{2g} \]

where:
- \( h_m \) = minor loss,
- \( h_i \) = velocity head, &
- \( k \) = minor loss friction factor.

### Illustrated Table

<table>
<thead>
<tr>
<th>Component</th>
<th>Minor Friction Loss Coefficient, ( k )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gate Valve: 100% opened</td>
<td>0.39</td>
</tr>
<tr>
<td>75% opened</td>
<td>1.1</td>
</tr>
<tr>
<td>50% opened</td>
<td>4.8</td>
</tr>
<tr>
<td>25% opened</td>
<td>27</td>
</tr>
<tr>
<td>Globe Valve: opened</td>
<td>10</td>
</tr>
<tr>
<td>Angle Valve: opened</td>
<td>4.3</td>
</tr>
<tr>
<td>Butterfly Valve: opened</td>
<td>1.2</td>
</tr>
<tr>
<td>Check Valve</td>
<td>4.0</td>
</tr>
<tr>
<td>Coupling</td>
<td>0.10</td>
</tr>
<tr>
<td>90° Elbow</td>
<td>0.35</td>
</tr>
<tr>
<td>Expansion: 25% increase</td>
<td>0.16</td>
</tr>
<tr>
<td>100% increase</td>
<td>0.57</td>
</tr>
<tr>
<td>400% increase</td>
<td>0.92</td>
</tr>
<tr>
<td>Contraction: 20% reduction</td>
<td>0.18</td>
</tr>
<tr>
<td>50% reduction</td>
<td>0.37</td>
</tr>
<tr>
<td>80% reduction</td>
<td>0.49</td>
</tr>
<tr>
<td>Tee: line flow</td>
<td>0.35</td>
</tr>
<tr>
<td>Tee: branch flow</td>
<td>1.25</td>
</tr>
</tbody>
</table>

### Table: Friction Coefficient, \( C \)

<table>
<thead>
<tr>
<th>Pipe Material</th>
<th>Friction Coefficient, ( C )</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC</td>
<td>150</td>
</tr>
<tr>
<td>PE</td>
<td>140</td>
</tr>
<tr>
<td>Aluminum (with couplers)</td>
<td>130</td>
</tr>
<tr>
<td>Steel (new)</td>
<td>130</td>
</tr>
<tr>
<td>Galvanized steel (new)</td>
<td>120</td>
</tr>
<tr>
<td>Epoxy-coated steel</td>
<td>145</td>
</tr>
<tr>
<td>Cement asbestos</td>
<td>140</td>
</tr>
</tbody>
</table>