MEC516/BME516: Fluid Mechanics I

Chapter 3: Control Volume Analysis Part 11

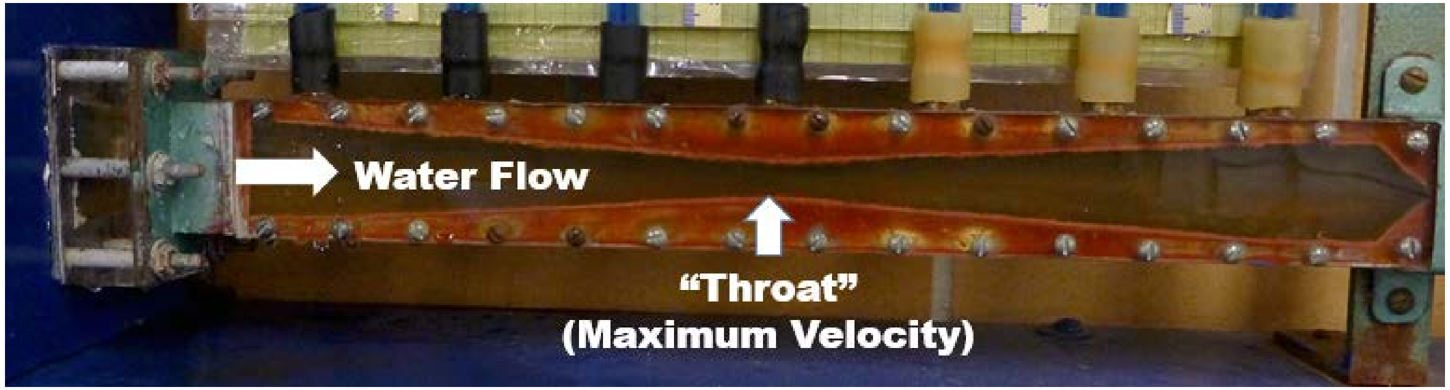
RYERSON UNIVERSITY
Department of Mechanical & Industrial Engineering

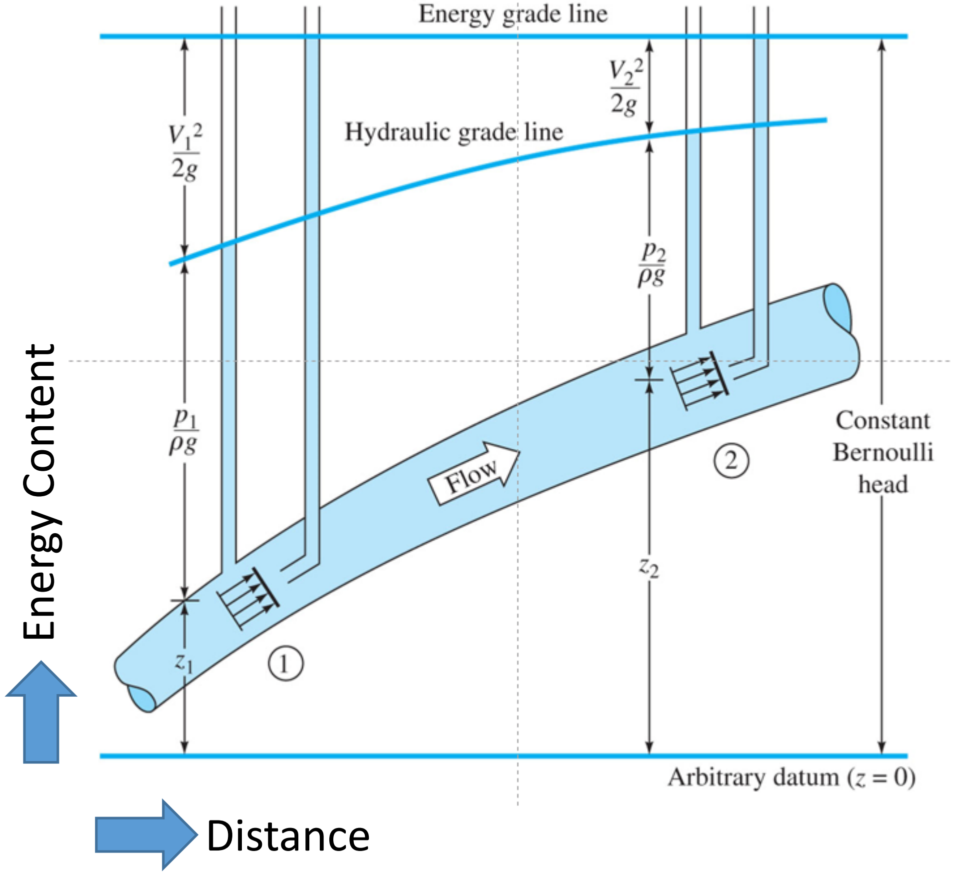
Overview

- ***Hydraulic Grade Line (HGL)*** and ***Energy Grade Line (EGL)***
  - Graphical representation of the Bernoulli equation
  - Grade lines provide insight into physics (energy transformations)

Examples

- Simple frictionless *Bernoulli*-type flows
- Application for real flows (with pressure losses etc.)
  - Flows described by *Steady Flow Energy Equation*
  - HGL and EGL presentation has been delayed





Definition of "Head"

- Recall: The Bernoulli equation (inviscid flow):

$$\frac{V^2}{2g} + \frac{p}{\gamma} + z = const$$

- Terms have units of height (m, ft) or "head"
- "Head" is the energy content of the flow per unit weight, (N-m/N)= m

$\frac{V^2}{2g}$ is called the *velocity head,* (m)

$\frac{p}{\gamma}$ is called the *pressure head,* (m)

z is called the *elevation head,* (m)

Total energy remains constant (along a streamline)

Daniel Bernoulli (1700-1782)

Hydraulic Grade Line (HGL) and Energy Grade Line (EGL)

$$\frac{V^2}{2g} + \frac{p}{\gamma} + z = const$$

- HGL and EGL are graphical representations of the energy components in the Bernoulli equation
- *Hydraulic Grade Line (HGL)* is a plot of the height

$$\frac{p}{\gamma} + z$$

  - z is plotted relative to an arbitrary datum
  - p/γ is plotted relative to pipe centre line

- HGL is the height the fluid would rise to in a piezometer
- Sometimes called *Piezometric Head Line*

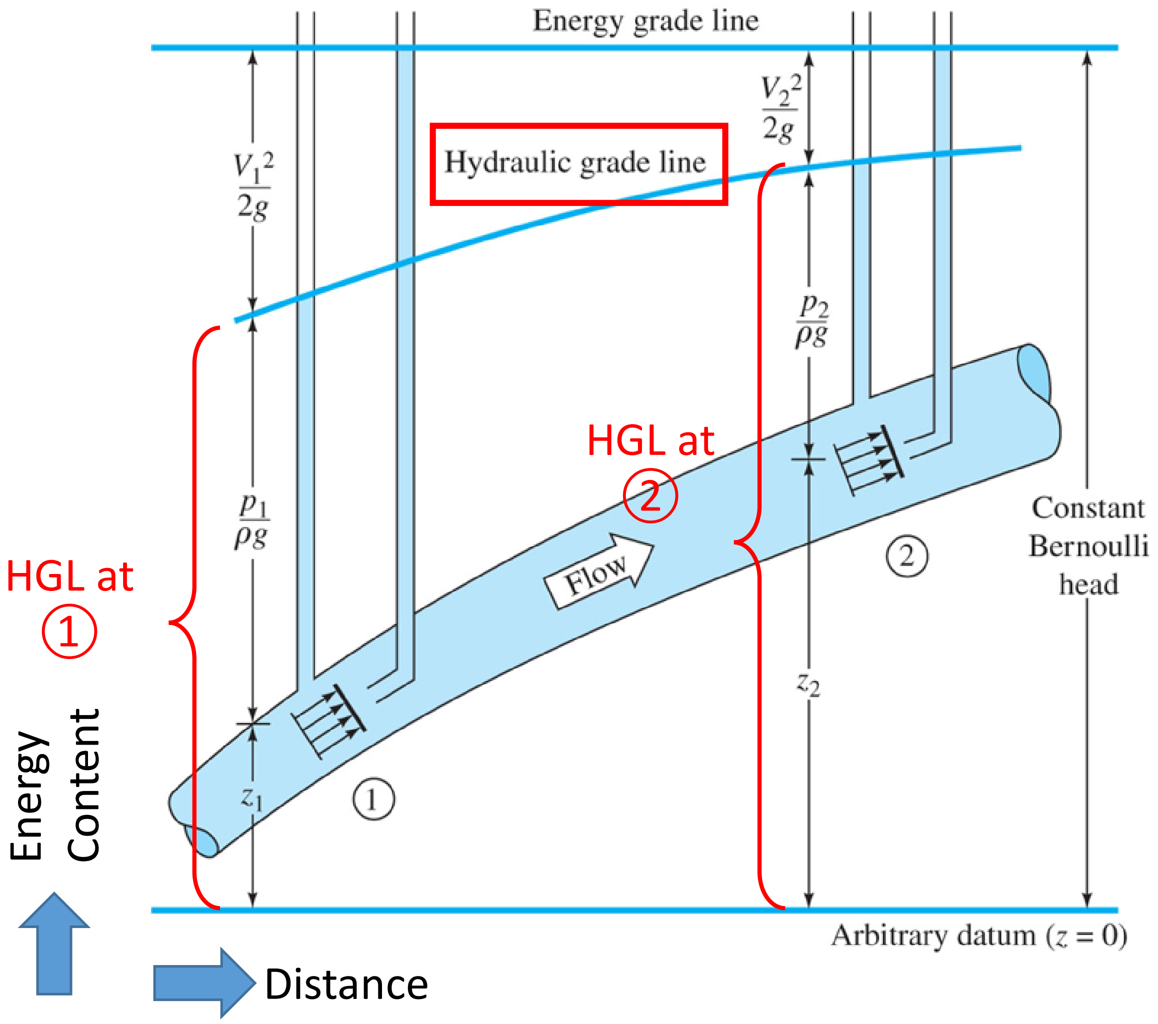


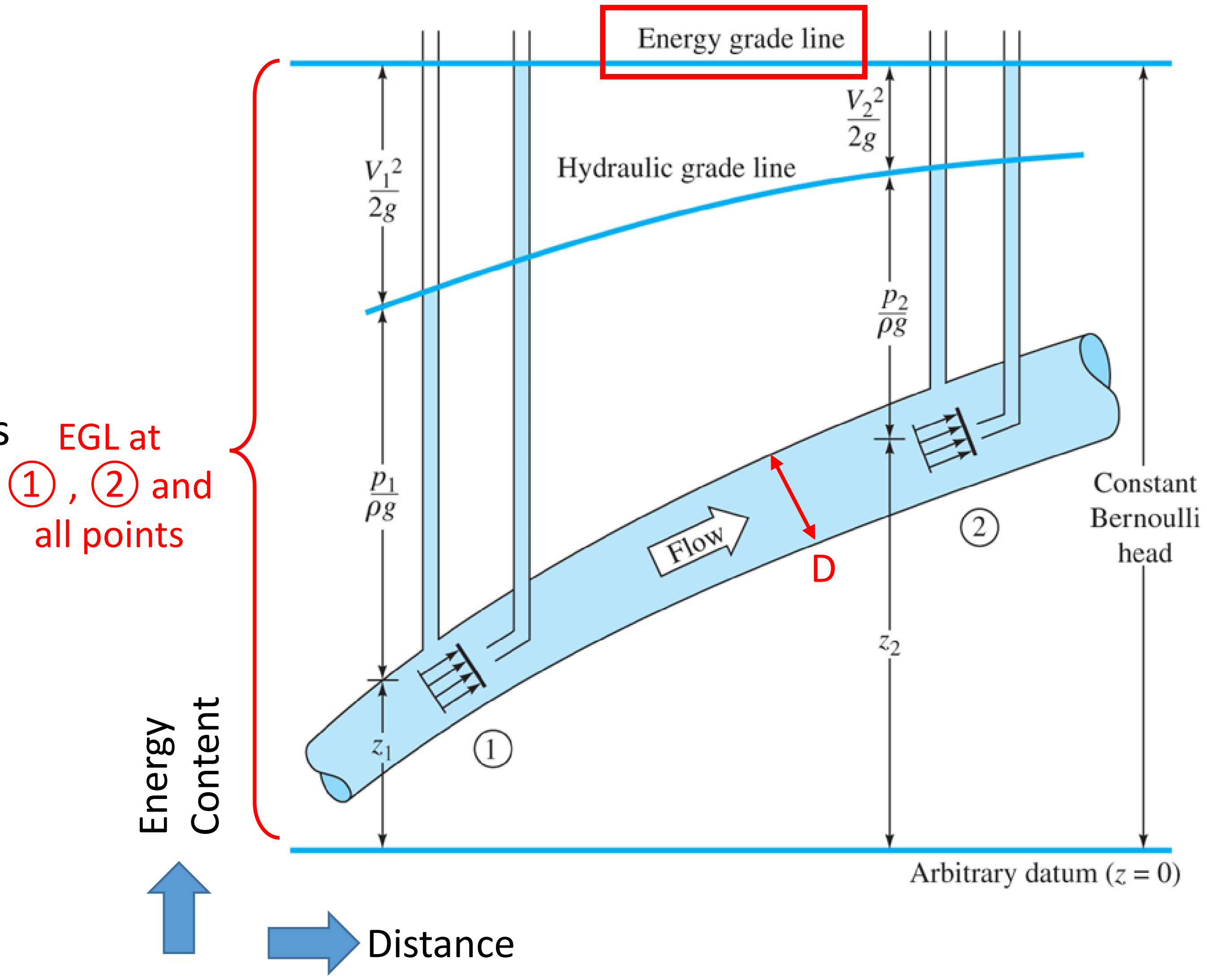
Fig. 3.14 HGL and EGL for flow in an inclined pipe

Hydraulic Grade Line (HGL) and Energy Grade Line (EGL)

- The *Energy Grade Line (HGL)* is the plot of the total energy content (Bernoulli constant)

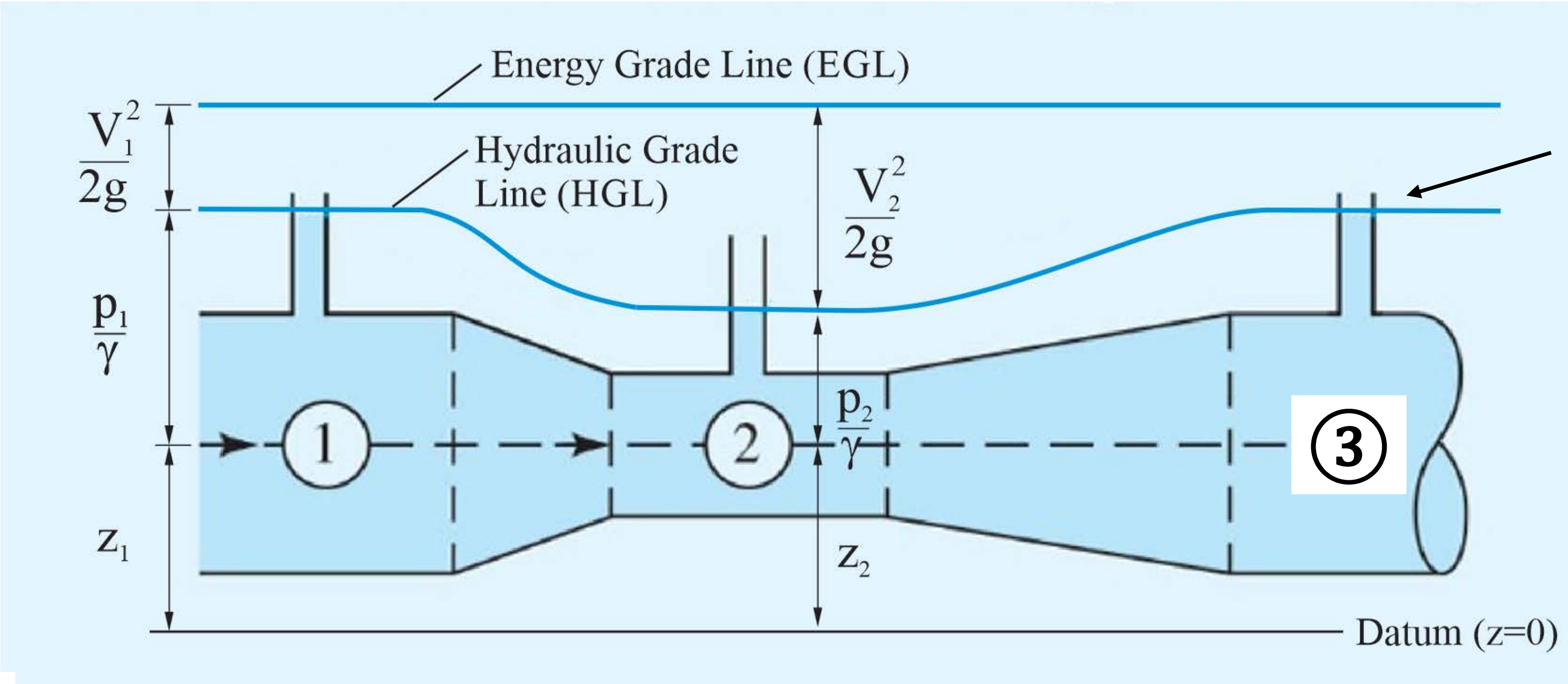
$$\frac{V^2}{2g} + \frac{p}{\gamma} + z$$

- For a inviscid (frictionless) flow, the energy grade line is a horizontal line (no energy losses or additions)
- EGL is constant; not "insightful" for inviscid flows
- EGL is more useful describe real flows with viscous losses, pumps, etc., i.e. Steady Flow Energy Equation
- Why does HGL increase in flow direction?
- Because the difference between the EGL and HGL is the velocity head; V decreases due to larger pipe



Example: Inviscid Flow Through a Venturi Meter

- Height of curves represents energy content (per unit weight)
- HGL corresponds to height of fluid in piezometers: $(z + p/\gamma)$
- EGL remains level in an ideal frictionless flow: $\left(z + \frac{p}{\gamma} + \frac{V^2}{2g}\right) = constant$ (no losses)



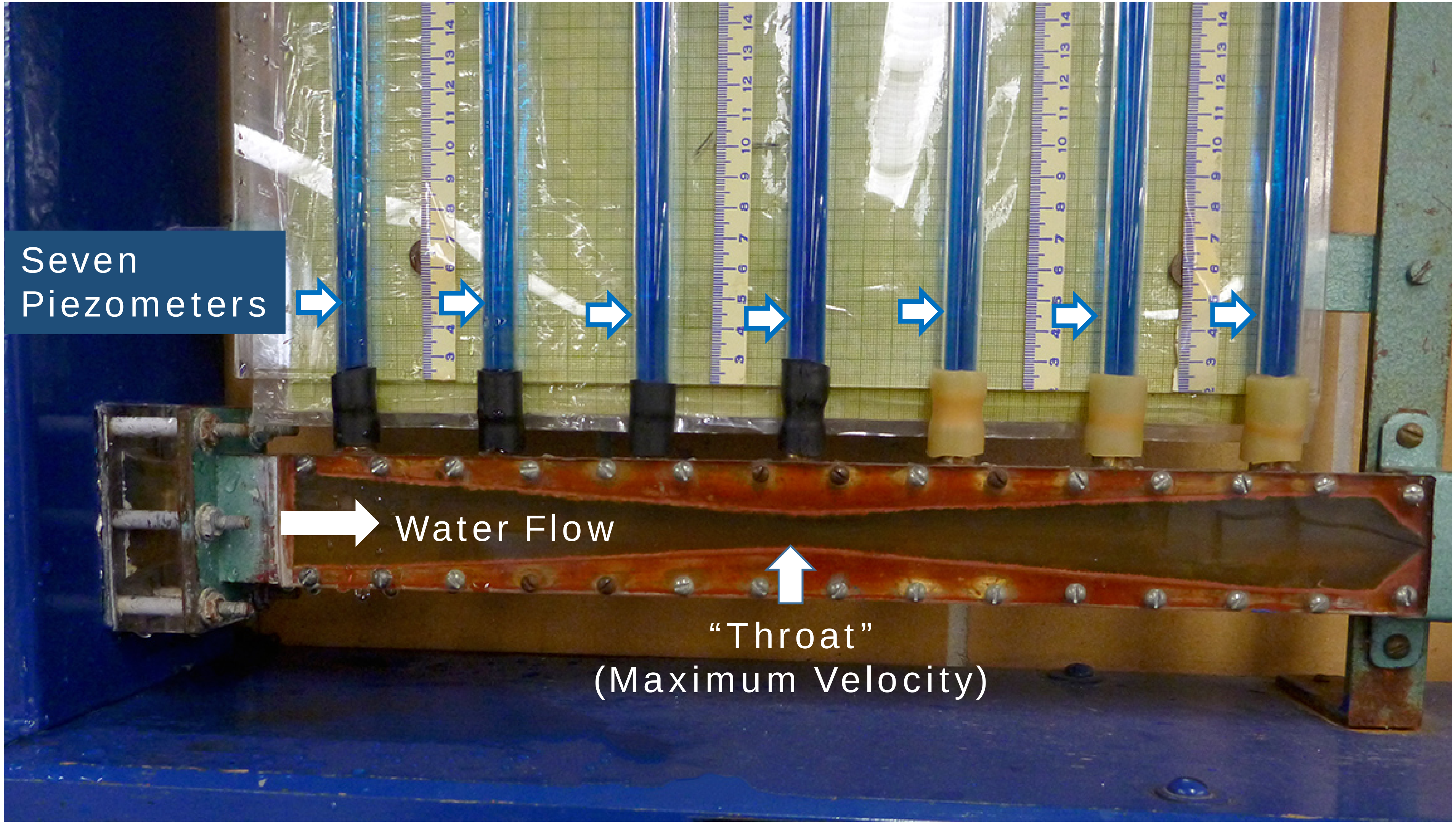
Ideal inviscid flow

$$z_1 + \frac{p_1}{\gamma} = z_3 + \frac{p_3}{\gamma}$$

- Piezometer has same height at ① & ③
- No pressure loss
- In real flows $p_3 < p_1$

Example: Real (Viscous) Flow Through a Venturi Meter

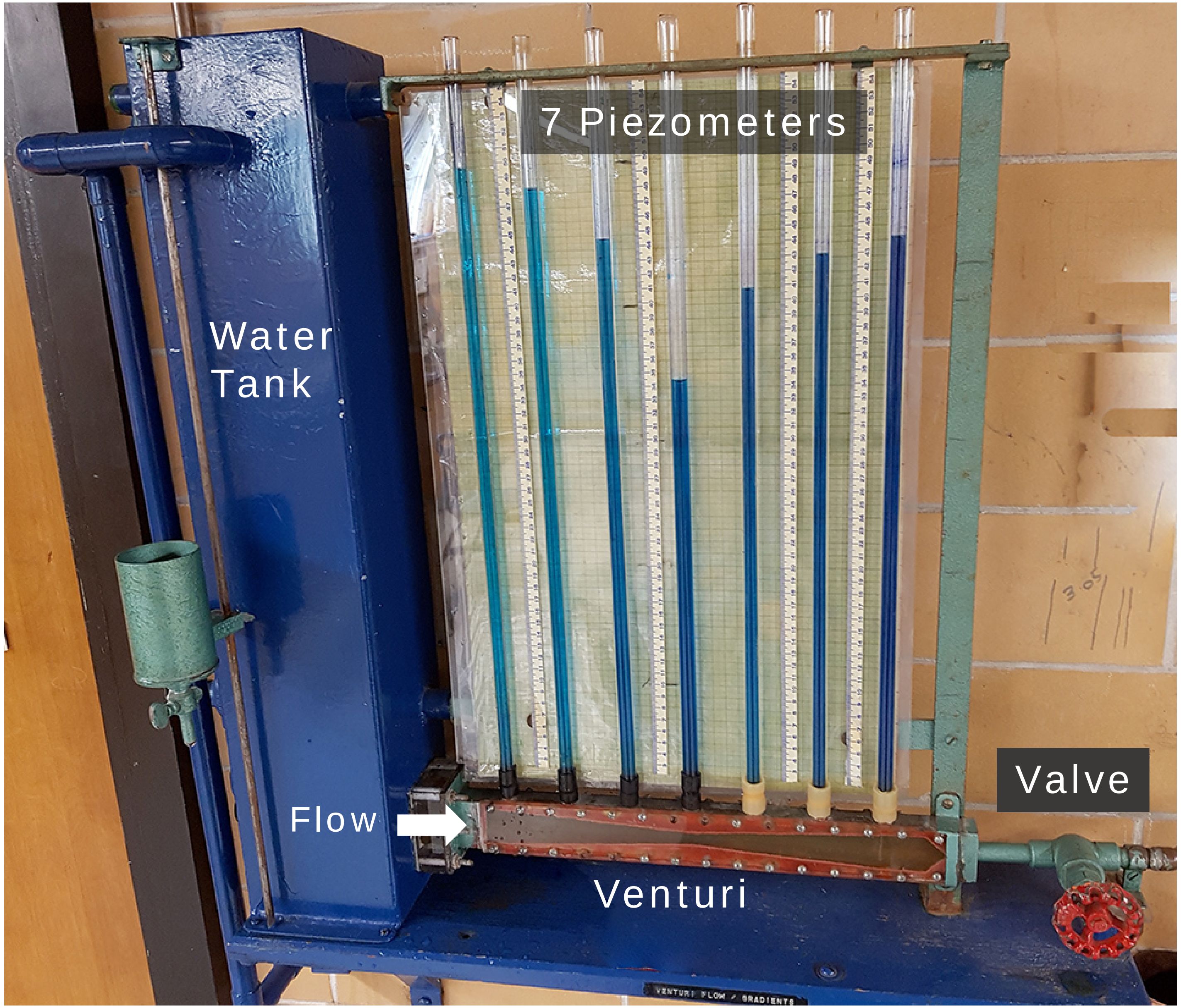
- Venturi Flow Meter (Lab 4)



Example: Real (Viscous) Flow Through a Venturi Meter

Experimental Setup

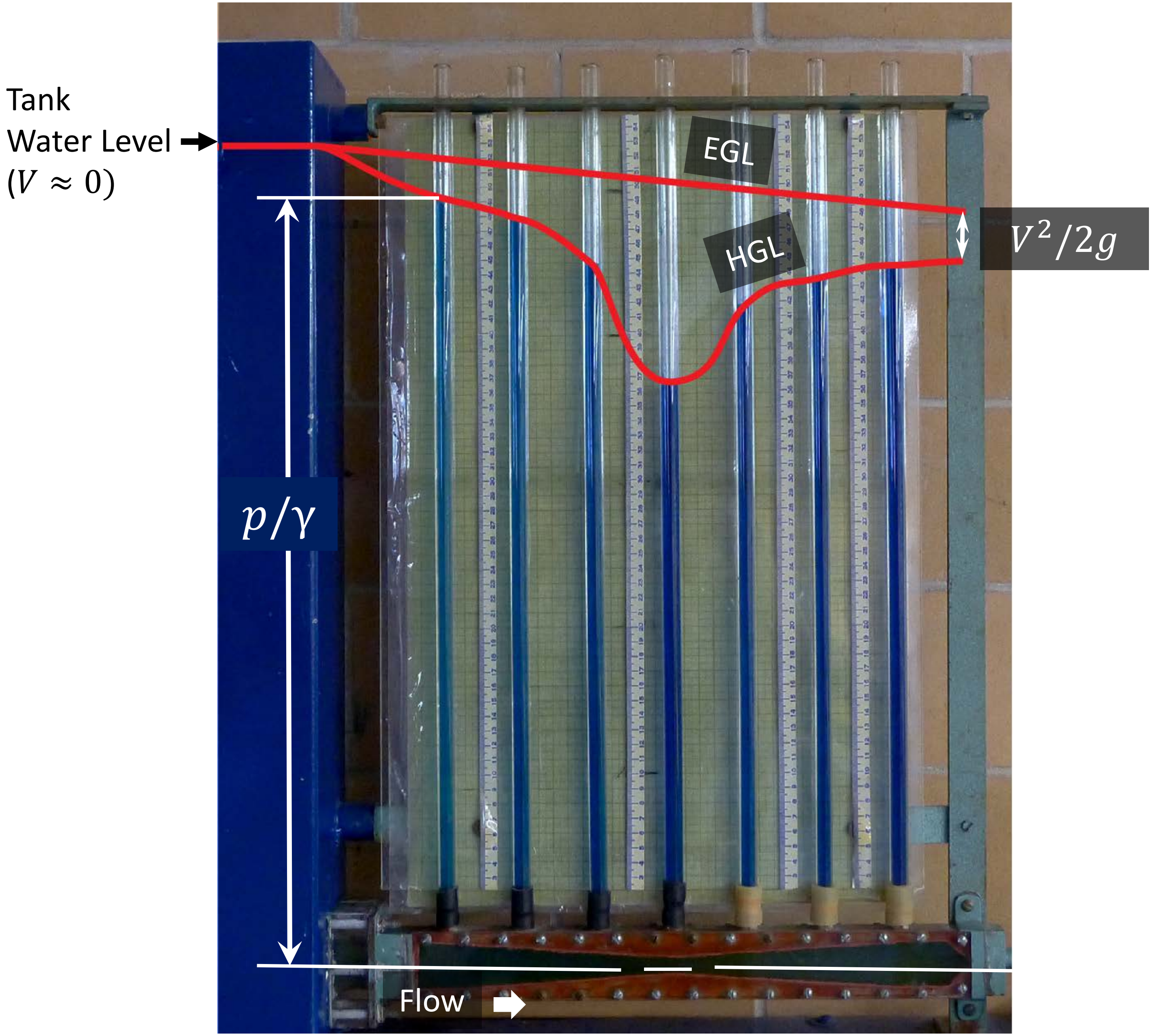
- Water tank (left)
- Venturi connected to side of tank
- Seven piezometers (open-ended pipes)
    - Blue dye (for visibility)
- Outlet valve (right) controls water flow rate



Video Demonstration: Venturi Flow Meter

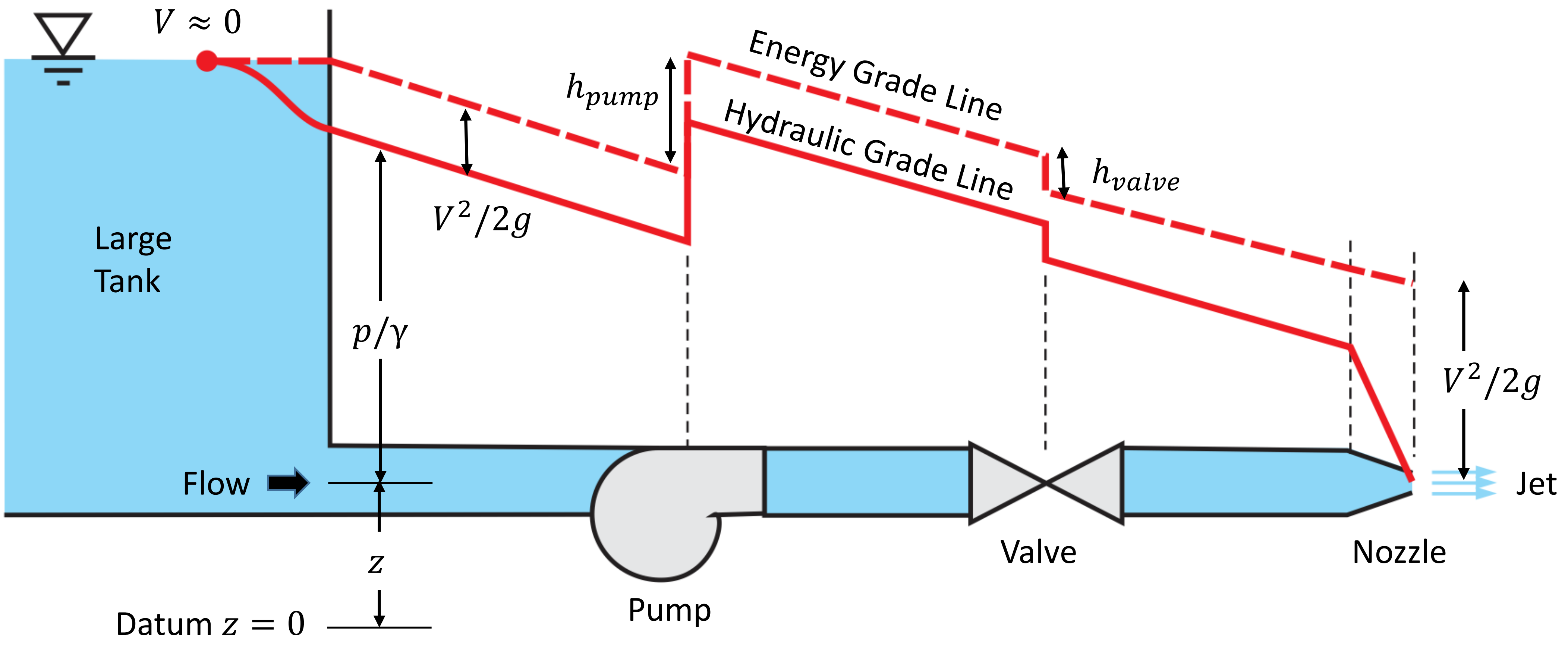
Example: Venturi Meter

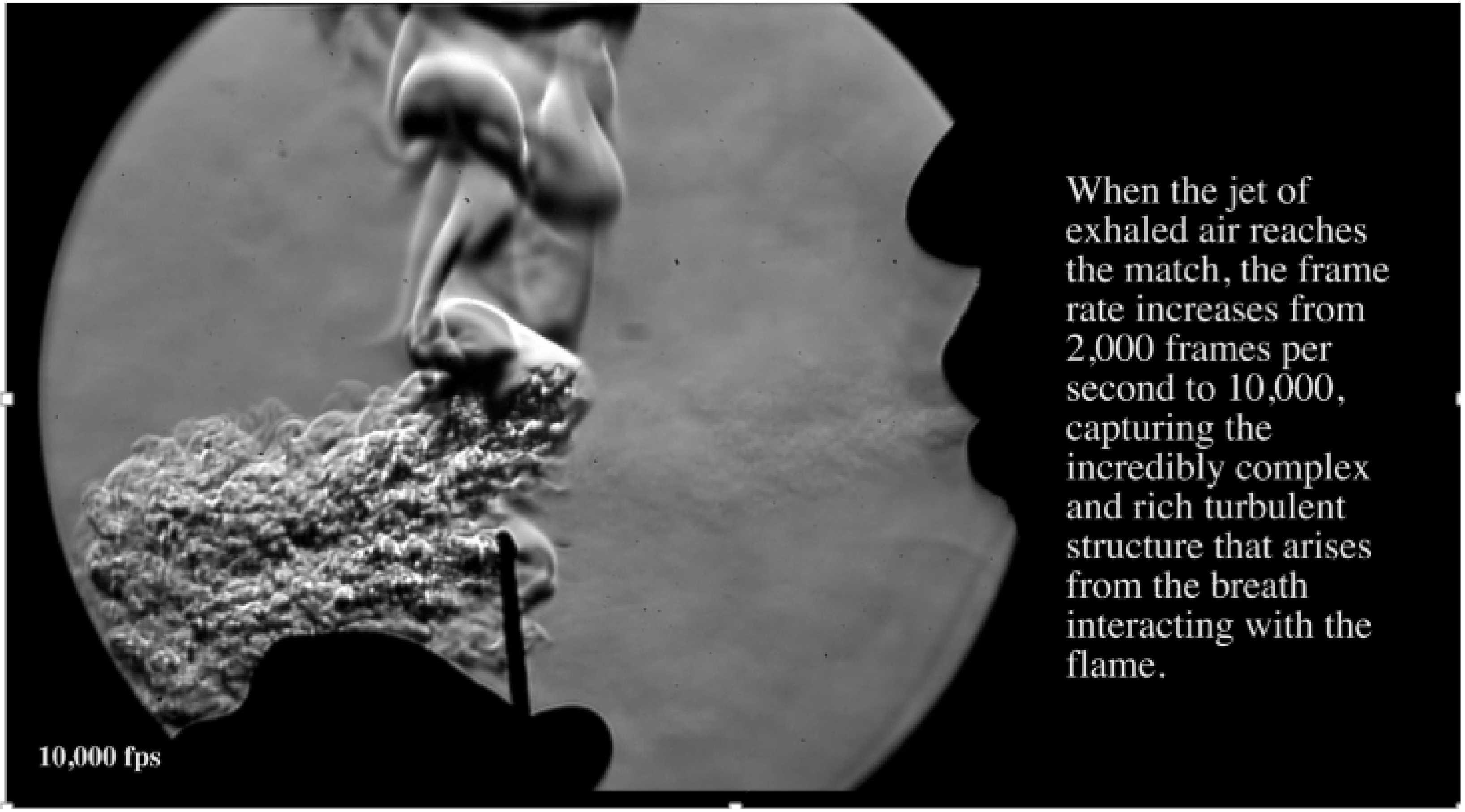
- Hydraulic Grade Line (HGL)
  - p/γ measured from pipe centre line
  - Min. pressure head at the “throat”
  - Incomplete “recovery” of pressure head
- Energy Grade Line (EGL)
  - EGL and HGL are coincident in the tank (where $V \approx 0$)
  - EGL is NOT horizontal in a viscous flow
  - Energy losses in flow direction (viscosity, turbulence)
  - Thus, EGL slopes downward in flow direction
  - Higher than HGL by the velocity head, $V^2/2g$



Example: HGL and EGL for a Piping System

- Flow in a long pipe, with pressure head loss ($h_{friction}$)
- Energy losses in the pipe will cause EGL to slope downward in the flow direction





High speed camera with Schlieren photography shows the density variations in the fluid.

Source: American Physical Society, Division of Fluid Mechanics, Video Gallery (http://www.aps.org/units/dfd/pressroom/videos/index.cfm)

END NOTES

Presentation prepared and delivered by Dr. David Naylor.