ESO204A, Fluid Mechanics and Rate Processes

Incompressible flows through pipes and ducts (Internal Flow)

Engineering applications of Fluid Mechanics

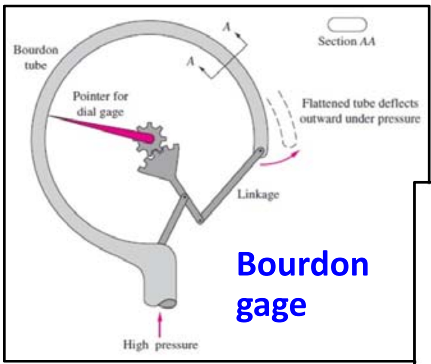
Chapter 6 of F M White
Chapter 8 of Fox McDonald

So far in this Chapter

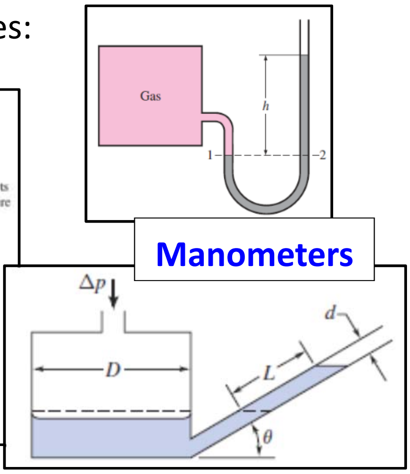
- Learned major and monor losses in pipe flow
- Learned series and parallel piping system
- Solved application-oriented problems in pipe flow; some of them require iterative solution

Measurements of pressure, velocity, flow rate

Pressure measuring devices:



Bourdon gage



Manometers

Consider a frictionless flow with the velocity and pressure of u, p

$$\text{Total head } h = \frac{p}{\rho g} + \frac{u^2}{2g} = \text{constant}$$

If the fluid is brought to rest

$$\text{Total head } h = \frac{p}{\rho g} + \frac{u^2}{2g} = \text{constant} = \frac{p_0}{\rho g}$$

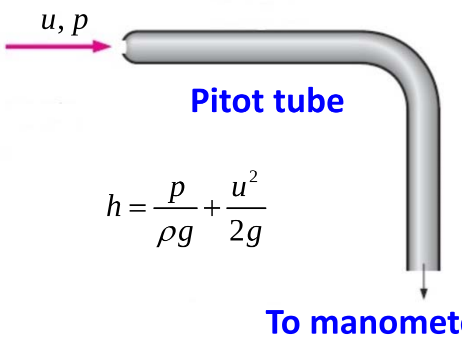
$$p_0 = p + \frac{1}{2}\rho u^2$$

Stagnation pressure

Static pressure

Dynamic pressure

Velocity measurements using Pitot-static tube



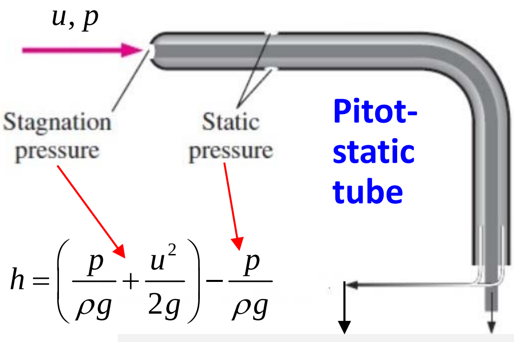
$$h = \frac{p}{\rho g} + \frac{u^2}{2g}$$

Insert the probe in the flow and record the manometer reading (h)

We find the velocity if we know the pressure

Pitot-static tube

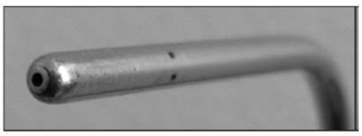
Insert the probe in the flow and record the differential manometer reading

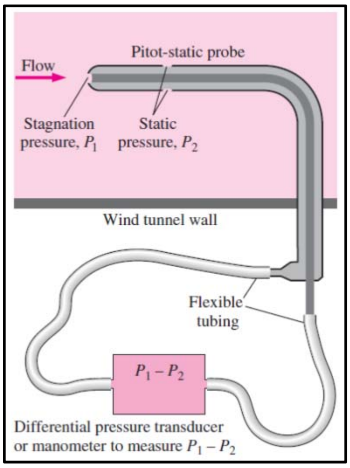


$$h = \left(\frac{p}{\rho g} + \frac{u^2}{2g}\right) - \frac{p}{\rho g}$$

$$h = \frac{u^2}{2g}$$

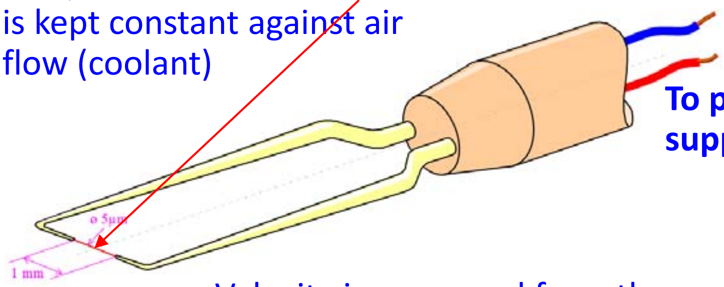
To differential manometer





Velocity measurements: Hot-wire anemometer

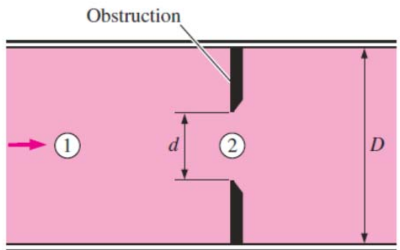
Temperature of the hot-wire is kept constant against air flow (coolant)



To power supply

Velocity is measured from the power required to maintain the wire temperature constant

Flow measurements: Obstruction flowmeter



Obstruct the flow

Measure the pressure-drop across obstruction

Use Bernoulli Eq.

$$\frac{p_1}{\rho g}+\frac{u_1^2}{2g}=\frac{p_2}{\rho g}+\frac{u_2^2}{2g}$$

$$D^2 u_1 = d^2 u_2$$

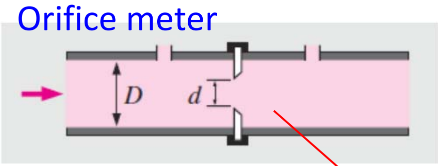
$$u_2=\sqrt{\frac{2\left(p_1-p_2\right)}{\rho\left(1-d^4/D^4\right)}}$$

$$Q = C_d A_2 u_2$$

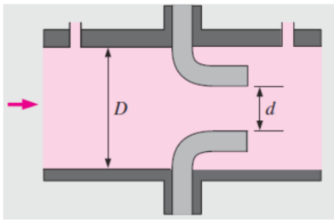
Discharge coefficient, obtained experimentally

Major design variations

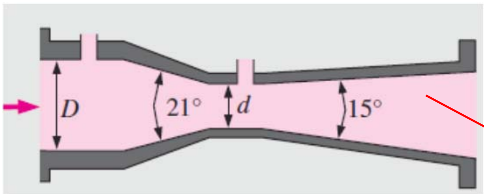
Orifice meter



Flow nozzle



Venturi meter



Ease of use, low cost

High accuracy

Hydraulic and Energy Grade lines

Recall $$\frac{p}{\rho g} + \frac{u^2}{2g} + z = H$$

Total head

Pressure head

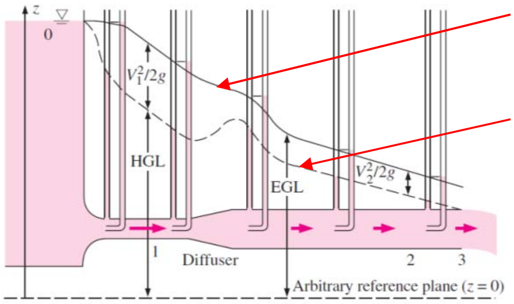
Velocity head

Elevation head

In a pipe flow H drops along flow direction, plot of H vs L is known as energy grade line

Piezometric head $$\frac{p}{\rho g} + z = H_{\mathrm{p}}$$

H_{p} vs L plot is known as hydraulic grade line

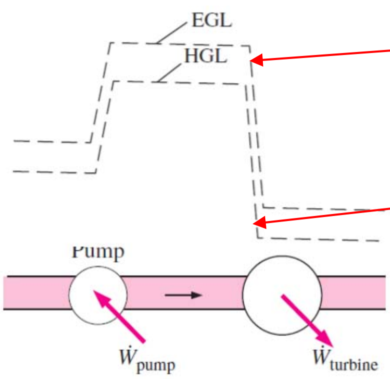


Energy grade line (EGL)

Hydraulic grade line (HGL)

EGL always drop along the flow direction, the same is also true for HGL if diameter remains constant

Slope of grade lines may be used to calculate the frictional losses



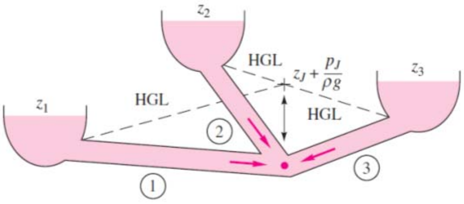
Energy grade line (EGL)

Hydraulic grade line (HGL)

Presence of pumps/turbine leads to sharp changes in grade lines

Hydraulic grade lines are useful tool for pipeline troubleshooting

Three reservoirs connected through smooth pipes



$d_1 = d_2 = d_3 = 100\text{cm}$

$L_1 = L_2 = L_3 = 100\text{m}$

$z_1 = 10\text{m},\ z_2 = 40\text{m}$

$z_3 = 20\text{m},\ z_J = 0$

Find Q_1, Q_2, Q_3

Assuming all flows are toward the junction

$$Q_1 + Q_2 + Q_3 = 0 \quad \Rightarrow u_1 + u_2 + u_3 = 0$$

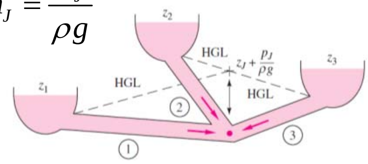
HGL: $h_J = z_J + \dfrac{p_J}{\rho g} = \dfrac{p_J}{\rho g}$

Energy Eqn. $\dfrac{p_1}{\rho g} + z_1 = \dfrac{p_J}{\rho g} + z_J + h_{f1} \quad \Rightarrow h_{f1} = z_1 - h_J$

$$h_{f1} = z_1 - h_J$$

$$\Rightarrow \frac{f_1 L_1}{d}\frac{u_1^2}{2g} = z_1 - h_J$$

$h_J = \dfrac{p_J}{\rho g}$



$$u_1 + u_2 + u_3 = 0$$

Similarly

$$\frac{f_2 L_2}{d}\frac{u_2^2}{2g} = z_2 - h_J \qquad \frac{f_3 L_3}{d}\frac{u_3^2}{2g} = z_3 - h_J$$

We have four Eqns., four unknowns

Start with a guess of h_J and update till convergence