Hydraulics Engineering 6713

Tutorial Questions

Dr. Leonard Lye
Professor of Civil Engineering
TUTORIAL 1
TURBULENT PIPE FLOW

1. In a chemical processing plant it is desired to deliver benzene at 50°C (rel. density 0.86) to point B with a pressure of 550 KN/m². A pump is located at point A 21 m below point B, and the 2 points are connected by 240 m of plastic pipe having an inside diameter of 50 mm. If the volume flow rate is 110 liters/min, calculate the required pressure at the outlet of the pump. How much would the required pressure change if welded steel pipes are used instead of plastic pipes? (µ = 0.00042 N-s/m²).

2. What diameter of cast iron pipe would be required to ensure that a discharge of 0.20 m³/s would not cause a head loss in excess of 0.01 m/ 100 m of pipe length? Assume water temperature of 20°C.

3. A 2000 m long commercial steel pipeline of 200 mm diameter conveys water at 20°C between two reservoirs, as shown in the Figure below. The difference in water level between the reservoirs is maintained at 50 m. Determine the discharge through the pipeline. Neglect the minor losses.

4. Compare answers for Q1, Q2, and Q3 using explicit equations.

5. Use the Hazen-Williams and Manning’s equations to solve Q1, Q2, and Q3.

6. Use Flowmaster to solve Q1, Q2, and Q3.
1. A 6-km-long, new cast-iron pipeline carries 320 litres/s of water at 30°C. The pipe diameter is 30 cm. Compare the head loss calculated from the:
   a. Hazen-Williams formula
   b. Manning formula
   c. Darcy-Weisbach formula.

2. Two reservoirs 1200 m apart are connected by a 50 cm smooth concrete pipe. If the two reservoirs have an elevation difference of 5 m, determine the discharge in the pipe by the:
   a. Hazen-Williams formula
   b. Manning formula
   c. Darcy-Weisbach formula.

3. An old pipe 2 m in diameter has a roughness of $\varepsilon=30$ mm. A 12-mm-thick lining would reduce the roughness to $\varepsilon=1$ mm. How much in annual pumping costs would be saved per kilometer of pipe for water at 20°C with discharge of $6 \text{ m}^3/\text{s}$? The pumps and motors are 80% efficient, and power costs 4 cents per kilowatt-hour.

4. What size commercial steel pipe is needed to convey 200 L/s of water at 20°C 5 km with a head drop of 4 m? The line connects two reservoirs, has a reentrant entrance, a submerged outlet, four standard elbows, and a globe valve.

5. What is the equivalent length of 50 mm diameter pipe, $f=0.022$, for a:
   a. re-entrant pipe entrance
   b. sudden expansion from 50 mm to 100 mm diameter
   c. globe valve and a standard tee?

6. Solve Q1 and Q1 using Flowmaster.
1. Sketch the energy grade line and the hydraulic grade line for the compound pipe shown below. Consider all the losses and the change in velocity and pressure heads.

2. Two sections of cast-iron pipe connected in series bring water from a reservoir and discharge it into air at a location 100 m below the water surface elevation in the reservoir through a globe valve. The first pipe section is 400 mm diameter and is 1000 m long, and the second pipe section is 200 mm diameter and 1200 m long. If the water temperature is 10°C, and square connections are used, determine the discharge. Sketch the EGL and HGL.

3. Two new cast-iron pipes in series connect two reservoirs. Both pipe are 300 m long and have diameters of 0.6 m and 0.4 m, respectively. The elevation of water surface in reservoir A is 80 m. The discharge of 10°C water from reservoir A to reservoir B is 0.5 m$^3$/s. Find the elevation of the surface of reservoir B. Assume a sudden contraction at the junction and a square-edge entrance.

4. Pipeline AB connects two reservoirs. The difference in elevation between the two reservoirs is 10 m. The pipeline consists of an upstream section, $D_1 = 0.75$ m and $L_1 = 1500$ m, and a downstream section, $D_2 = 0.5$ m and $L_2 = 1000$ m. The pipes are cast-iron and are connected end-to-end with a sudden reduction of area. Assume the water temperature at 10°C. Compute the discharge capacity using the graphical approach.
1. A two-loop pipe network has node designations as shown below. Inflows of 0.4 m$^3$/s and 0.45 m$^3$/s enter points A and B, respectively. Equal withdrawals are made at points C, D, and F. The pipe characteristics are as follows:

<table>
<thead>
<tr>
<th>Pipe</th>
<th>Length (m)</th>
<th>Diameter (m)</th>
<th>Friction factor $f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>500</td>
<td>0.4</td>
<td>0.017</td>
</tr>
<tr>
<td>BC</td>
<td>400</td>
<td>0.5</td>
<td>0.016</td>
</tr>
<tr>
<td>AF</td>
<td>650</td>
<td>0.5</td>
<td>0.014</td>
</tr>
<tr>
<td>BE</td>
<td>750</td>
<td>0.35</td>
<td>0.015</td>
</tr>
<tr>
<td>CD</td>
<td>700</td>
<td>0.4</td>
<td>0.013</td>
</tr>
<tr>
<td>DE</td>
<td>550</td>
<td>0.5</td>
<td>0.016</td>
</tr>
<tr>
<td>EF</td>
<td>900</td>
<td>0.6</td>
<td>0.015</td>
</tr>
</tbody>
</table>

2. Determine the flow into and out of each reservoir in the Figure below if the connecting pipes are made of the same material with $\varepsilon = 0.05$ mm and water temperature at 20°C. The pipe characteristics are as follows:

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Elevation (m)</th>
<th>Pipe</th>
<th>Length (m)</th>
<th>Diameter (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100</td>
<td>a</td>
<td>3000</td>
<td>0.8</td>
</tr>
<tr>
<td>B</td>
<td>80</td>
<td>b</td>
<td>4000</td>
<td>1.2</td>
</tr>
<tr>
<td>C</td>
<td>70</td>
<td>c</td>
<td>5000</td>
<td>0.6</td>
</tr>
</tbody>
</table>
3. Four pipes are connected in parallel. Their characteristics are as follows:

<table>
<thead>
<tr>
<th>Pipe No.</th>
<th>Diameter (m)</th>
<th>Length (m)</th>
<th>Roughness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.15</td>
<td>3000</td>
<td>0.06</td>
</tr>
<tr>
<td>2</td>
<td>0.30</td>
<td>3000</td>
<td>0.06</td>
</tr>
<tr>
<td>3</td>
<td>0.45</td>
<td>3000</td>
<td>0.09</td>
</tr>
<tr>
<td>4</td>
<td>0.60</td>
<td>3000</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Determine the discharge through each pipe if the total flow is 1.4 m$^3$/s. Assume that the pipe flow is fully turbulent.

Assume fully turbulent flows.

4. Two reservoirs have a difference in elevation of 6 m and are connected by a pipeline which consists of a single 600 mm diameter pipe 3000 m long, feeding a junction from which 2 pipes, each 300 mm diameter and 3000 m long, lead in parallel to the lower reservoir. If $f = 0.04$, calculate the flow rate between reservoirs.

5. Solve Q1, Q2, Q3, and Q4 using WaterCad.
TUTORIAL 5
UNIFORM FLOWS IN OPEN CHANNELS

1. The cross-section of a canal is as shown below. The canal slope is 1/4000.
   a. Determine the discharge if Chezy’s C is 60 m$^{1/2}$/s.
   b. Determine the discharge if Manning’s n is 0.025.
   c. What value of C corresponds to n=0.025?
   d. What value of n corresponds to C = 60 m$^{1/2}$/s?

2. A trapezoidal canal has a bottom width of 5 m, side slopes of 1:2 and a slope of 0.0004.
   Manning’s n is 0.014. The depth is 2 m. Determine the discharge.

3. Calculate for the same canal as in Problem 2 the water depth when the discharge is 75 m$^3$/s.
   Answer must be accurate to the nearest cm.

4. A reinforced concrete aqueduct of rectangular cross-section is to be designed to carry 10 m$^3$/s
   with a velocity of 2 m/s. Determine the water depth and the width of the cross-section so that
   the required slope of the aqueduct is minimized.

5. Design a trapezoidal cross-section canal with an area of 60 m$^2$, a hydraulic radius of 2 m, and
   side slopes of 1:3.

6. Solve Q1, Q2, and Q3 using Flowmaster.
TUTORIAL 6
ENERGY CONCEPTS IN OPEN CHANNEL FLOW

1. Water is flowing in a rectangular channel at a velocity of 3 m/s and a depth of 2.5 m. Determine the changes in water surface elevation for the following alterations in the channel bottom:
   a. An increase (upward step) of 20 cm, neglecting losses.
   b. The maximum increase allowable for the specified upstream flow conditions to remain unchanged, neglecting losses.
   c. A “well-designed” decrease (downward step) of 20 cm.

2. Water is flowing in a rectangular channel whose width is 5 m. The depth of flow is 2 m and the discharge is 25 m$^3$/s. Determine the changes in depth for the following alterations in the channel width:
   a. An increase of 50 cm, neglecting losses.
   b. A decrease of 25 cm, assuming a “well-designed” transition.
   c. The maximum decrease allowable for the specified upstream flow conditions to remain unchanged, neglecting losses.

3. A lake discharges into a steep channel. At the channel entrance the lake level is 2.5 m above the channel bottom. Neglecting losses, find the discharge for the following geometries:
   a. Rectangular section, $b = 4$ m.
   b. Trapezoidal section, $b = 3$ m, side slopes = 1:2.5.
1. A 3 m wide rectangular channel carries 15 m$^3$/s of water at 0.6 m depth before entering a hydraulic jump. Compute the downstream water depth and the critical depth.

2. A long rectangular channel 3 m wide carries a discharge of 15 m$^3$/s. The channel slope is 0.004 and the Manning’s roughness coefficient is 0.01. At a certain point in the channel where the flow reaches the normal depth,
   a. Determine the state of the flow. Is it supercritical or subcritical?
   b. If a hydraulic jump takes place at this depth, what is the sequent depth at the jump?
   c. Estimate the energy head loss through the jump.

3. A spillway, as shown, has a flow of 3 m$^3$/s per meter of width occurring over it. What depth $y_2$ will exist downstream of the hydraulic jump? Assume there is no energy loss over the spillway.
1. A rectangular concrete conduit is to be used as a culvert on a slope of 0.02. The culvert is 15 m long and has a cross-section of 2.13 m x 2.13 m. If the tail water elevation is 1.8 m above the crown at the outlet, determine the head water elevation necessary to pass a 10 m$^3$/s discharge. Assume a square-edged entrance ($K_e = 0.5$).

2. A culvert is 11 m long and has upstream and downstream inverts of 263.4 and 263.1 meters, respectively. The downstream tailwater is below the downstream pipe invert.
   a. For a square-edged entrance and Manning’s $n$ of 0.013, what is the minimum diameter for a concrete circular culvert (in mm) required to pass 1.4 m$^3$/s under a roadway with a maximum allowable headwater elevation of 265.2 m?
   b. What is the headwater elevation for the selected culvert?

3. Twin 1220 by 910 mm box culverts ($n = 0.013$, 90° and 15° wingwall flares entrance) carry 8.5 m$^3$/s along a 31 m length of pipe constructed at a 1.0 % slope. The tailwater depth is 0.61 m.
   a. What is the headwater depth?
   b. Are the culverts under inlet or outlet control conditions?

4. A 12.2 m long 920 by 570 mm concrete arch pipe ($n = 0.013$, groove-end with headwall entrance) constructed at a 0.8 percent slope carries 1.84 m$^3$/s.
   a. If there is a constant tailwater depth of 0.3 m, what is the headwater depth for both inlet and outlet control conditions?
   b. Is the culvert flowing under inlet or outlet control conditions?
   c. What would be the result if the tailwater was 0.5 m deeper?

5. Twin culverts are proposed to discharge 6.5 m$^3$/s. The culverts will be 36.6 m long and have inverts of 20.1 and 19.8 m. The design engineer analyzed the following three culvert systems. Which of the following proposed culverts will result in the highest headwater elevation? The lowest? Tailwater elevation is below the downstream invert.
   a. 1200 mm circular concrete pipes ($n = 0.013$, square-edged entrance);
   b. 1200 x 910 mm concrete box culverts ($n = 0.013$, 90° and 15° wingwall flares entrance);
   c. 1630 x 1120 mm steel and aluminum arches ($n = 0.025$ and $K_e = 0.5$).
   [Hint: Use Culvert-Master to either solve the problems or use it to check your solutions].
1. From the manufacturer’s data, a pump of 254 mm impeller diameter has a capacity of 76 L/s at a head of 18.6 m when operating at a speed of 900 rpm. It is desired that the capacity be about 95 L/s at the same efficiency. Determine the adjusted speed of the pump and the corresponding head.

2. The following performance curves were obtained from a test on a 216 mm double entry centrifugal pump moving water at a constant speed of 1350 rpm:

<table>
<thead>
<tr>
<th>Q (m³/min)</th>
<th>0</th>
<th>0.454</th>
<th>0.905</th>
<th>1.36</th>
<th>1.81</th>
<th>2.27</th>
<th>2.72</th>
<th>3.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>H (m)</td>
<td>12.2</td>
<td>12.8</td>
<td>13.1</td>
<td>13.4</td>
<td>13.4</td>
<td>13.1</td>
<td>12.2</td>
<td>9.0</td>
</tr>
<tr>
<td>η</td>
<td>0</td>
<td>0.26</td>
<td>0.46</td>
<td>0.59</td>
<td>0.70</td>
<td>0.78</td>
<td>0.78</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Plot H vs. Q and η vs. Q. If the pump operates in a system whose demand curve is given by \( H = 5 + Q^2 \), find the operating point of the pump and the power required. In the demand curve, Q is given in m³/min.

3. With reference to the pump data in Problem 2, if the pump is run at 1200 rpm, find the discharge, head, and required power.

4. Water is pumped between two reservoirs in a pipeline with the following characteristics: \( D = 300 \text{ mm}, L = 70 \text{ m}, f = 0.025, \Sigma K = 2.5 \). The radial flow pump characteristic curve is approximated by the formula:

\[
H_p = 22.9 + 10.7Q - 111Q^3
\]

Where \( H_p \) is in meters and Q is in m³/s. Determine the discharge Q and pump head H for the following situations:

a. Total static head = 15 m, one pump placed in operation;
b. Total static head = 15 m, with two identical pumps operating in parallel;
c. Total static head = 25 m.
5. A pumping system is to deliver 28.3 L/s of water at 15°C. The suction line is 152 mm in diameter in a 91 m long cast iron pipe. The suction inlet is 6 m above the reservoir level. The atmospheric pressure of 101 kPa exists over the reservoir. The required NPSH of the pump is 2 m. Determine whether the system will have a cavitation problem. (Vapour pressure at 15°C is 16.8 kPa, kinematic viscosity of water is 1.14 x 10^{-6} m^2/s).