A homeowner plans to pump water from a stream in their backyard to water their lawn. A schematic of the pipe system is shown in the figure.

Details of the system are given in the following table. The design flow rate for the system is $2.5 \times 10^{-4} \text{ m}^3/\text{s}$.

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>water density</td>
<td>$1000 \text{ kg/m}^3$</td>
</tr>
<tr>
<td>water dynamic viscosity</td>
<td>$1 \times 10^{-3} \text{ kg/(m.s)}$</td>
</tr>
<tr>
<td>inlet pipe length</td>
<td>2 m</td>
</tr>
<tr>
<td>inlet pipe diameter</td>
<td>2.5 cm</td>
</tr>
<tr>
<td>inlet pipe material</td>
<td>drawn tubing</td>
</tr>
<tr>
<td>hose length</td>
<td>two 15.25 m lengths</td>
</tr>
<tr>
<td>hose diameter</td>
<td>1.3 cm</td>
</tr>
<tr>
<td>hose roughness</td>
<td>smooth</td>
</tr>
<tr>
<td>pipe inlet loss coefficient</td>
<td>0.8</td>
</tr>
<tr>
<td>inlet pipe-to-pump coupling loss coefficient</td>
<td>0.1</td>
</tr>
<tr>
<td>pump-to-hose coupling loss coefficient</td>
<td>0.2</td>
</tr>
<tr>
<td>hose-to-hose coupling loss coefficient</td>
<td>0.5</td>
</tr>
<tr>
<td>pressure drop across the sprinkler</td>
<td>$210 \text{ kPa at } 2.5 \times 10^{-4} \text{ m}^3/\text{s flow rate}$</td>
</tr>
<tr>
<td>sprinkler nozzle exit diameter</td>
<td>4 mm</td>
</tr>
</tbody>
</table>

1. What is the loss coefficient for the sprinkler at design conditions? Base the sprinkler loss coefficient on the velocity just upstream of the sprinkler. $K_{\text{sprinkler}} = 118$

2. What is the friction factor for the hose? $f_{\text{hose}} = 0.0244$

3. What is the velocity head, including the kinetic energy correction factor, at the sprinkler exit?

$$\frac{\alpha \frac{V^2}{2g}}{\text{sprinkler exit}} = 20.2 \text{ m}$$

For the next two questions, assume that the loss coefficient for the sprinkler is 100 and the friction factor for the hose is 0.01.

4. What is the total minor head loss in the system? $H_{\text{minor}} = 21.5 \text{ m}$

5. What is the total major head loss in the system? $H_{\text{major}} = 10.4 \text{ m}$

For the next question, assume that the velocity head at the sprinkler exit, including the kinetic energy correction factor, is 10 m and the total head loss is 10 m.

6. What is the shaft head required to operate the system at the design flow rate? $H_s = 55.1 \text{ m}$

For the next question, assume that the shaft head required to operate the system at the design flow rate is 100 m.

7. What power must be supplied to the pump if the pump is 65% efficient? $W_{\text{into, pump}} = 35 \text{ W}$
It rains during the construction of a building and water fills a recently excavated pit to a depth, \( h = 0.5 \text{ m} \). In order to continue construction, the water must first be pumped out of the pit. A hose with a length of \( L = 50 \text{ m} \), a diameter of \( D = 2.5 \times 10^{-2} \text{ m} \), and a surface roughness of \( \varepsilon = 5.0 \times 10^{-5} \text{ m} \) is attached to a pump. Note that the kinematic viscosity of the water is \( \nu = 1.005 \times 10^{-6} \text{ m}^2/\text{s} \) and the density is \( \rho = 1000 \text{ kg/m}^3 \).

a. If the pump is placed at the pit’s surface (figure a), what is the maximum depth of the pit, \( H \), for which water can be pumped out at a velocity of \( V = 1 \text{ m/s} \) without causing cavitation in the pipe? The vapor pressure of water for the current temperature is \( p_v = 2.337 \text{ kPa} \) (absolute pressure) and atmospheric pressure is \( p_{\text{atm}} = 101 \text{ kPa} \) (absolute pressure).

b. If the pump is placed at the bottom of the pit (figure b), what is the maximum depth of the pit, \( H \), for which water can be pumped out at a velocity of \( V = 1 \text{ m/s} \)? Assume that the pump supplies a power of \( P = 200 \text{ W} \) to the fluid.

Answer(s):
7.55 m, 39.0 m
Determine the power, in W, extracted by the turbine in the system shown below. The pipe entrance is sharp-edged and the volumetric flow rate is 0.004 m$^3$/s. The density of water is 998 kg/m$^3$ and the kinematic viscosity is 1.005e-6 m$^2$/s.

\[
\text{Answer(s):}
\]

-807 W (807 W extracted)
For straightening and smoothing an air flow in a 50 cm diameter duct, the duct is packed with a “honeycomb” of 30 cm long, 4 mm diameter thin straws. The inlet flow is air moving at an average velocity of 6 m/s. Estimate the pressure drop across the honeycomb. The density of the air is 1.2 kg/m³ and the kinematic viscosity is 1.5e-5 m²/s. You may neglect inlet and outlet minor losses.

\[ \Delta p = -64.8 \text{ Pa} \]
A train travels through a tunnel as shown in the figure. The train and tunnel are both circular in cross section. The tunnel has a diameter of $D=3\text{ m}$, a total length of $L=2000\text{ m}$, and walls comprised of concrete. The clearance between the train and the tunnel wall is small so that it may be assumed that the air in front of the train is pushed through the tunnel with the same speed as the train, $V=20\text{ m/s}$.

1. Determine the pressure difference between the front and rear of the train when the train is a distance, $x$, from the tunnel entrance.
2. Determine the power, $P$, required to produce the air flow in the tunnel when the train is a distance, $x$, from the tunnel entrance.

$\Delta p = 2560\text{ Pa}$, $360\text{ kW}$
Gasoline at 20 °C is being siphoned from a tank through a rubber hose having an inside diameter of 25 mm. The roughness for the hose is 0.01 mm.
1. What is the volumetric flow rate of the gasoline through the hose?
2. What is the minimum pressure in the hose and where does it occur?
You may neglect minor losses. The kinematic viscosity of gasoline is 4.294e-7 m²/s.

**Answer(s):**
1.57e-3 m³/s; 75.9 kPa (abs)
According to an appliance manufacturer, the 4 in diameter galvanized iron vent on a clothes dryer is not to contain more than 20 ft of pipe and four 90° elbows. Under these conditions, determine the air flow rate if the gage pressure within the dryer is 1.04 psi. You may assume the following:

- Kinematic viscosity of air: 1.79e-4 ft²/s
- Density of air: 2.20e-3 slugs/ft³
- \( K_{90°\, \text{bend}} = 1.5 \)
- \( K_{\text{entrance}} = 0.5 \)
- \( K_{\text{exit}} = 0 \) (discharges into atmosphere)

Answer(s):
0.882 ft³/s
Water at 10 °C (kinematic viscosity of 1.307*10^-6 m^2/s) is to flow from a roof-top reservoir to a tanker truck through a cast iron pipe (roughness of 0.26 mm) of length 20 m at a flow rate of 0.0020 m^3/s. The roof-top tank water level is located 2 m above the tanker truck fluid level. The system contains a sharp-edged entrance, six threaded 90° elbows, and a sharp-edged exit. Determine the required pipe diameter for the given flow conditions.

Answer(s):

0.045 m
Pipe flows from a container as shown in the figure. Determine the loss coefficient needed in the valve if the water is to “bubble up” a distance $h$ above the outlet pipe.

$H_1 = 45$ in  
$L_1 = 18$ in  
$L_2 = 32$ in  
$H_2 = 2$ in  
$h = 3$ in

The pipe is $\frac{1}{2}$ in diameter galvanized iron pipe with threaded fittings.

Answer(s):
5.9
A liquid with a specific gravity of 0.95 flows at an average velocity of 10 m/s through a horizontal smooth tube of diameter 5 cm. The fluid pressure is measured at 1 m intervals along the pipe as follows:

<table>
<thead>
<tr>
<th>x [m]</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>p [kPa]</td>
<td>304</td>
<td>273</td>
<td>255</td>
<td>240</td>
<td>226</td>
<td>213</td>
<td>200</td>
</tr>
</tbody>
</table>

a. Estimate the average wall shear stress, in Pa, in the fully developed region of the pipe.

b. What is the approximate wall shear stress between stations 1 and 2? State any significant assumptions you make.

Answer(s):
163 Pa; 388 Pa
The tailrace (discharge pipe) of a hydro-electric turbine installation is at an elevation, $h$, below the water level in the reservoir:

The frictional losses in the penstock (the pipe leading to the turbine) and the tailrace are represented by the loss coefficient, $k$, based on the mean velocity, $U$, in those pipes (which have the same cross-sectional area, $A$). The flow discharges to atmospheric pressure at the exit from the tailrace. The water density is denoted by $\rho$ and the acceleration due to gravity by $g$.

a. What is the drop in total head across the turbine?
b. What is the power developed by the turbine assuming that it is 90% efficient?
c. What is the optimum velocity, $U_{\text{opt}}$, which will produce the maximum power output from the turbine assuming that $h$, $k$, $A$, $\rho$, and $g$ are constant?

**Answer(s):**

$$H_s = \frac{U^2}{2g}(1 + k) - h$$

$$P_{\text{extracted}} = -0.9 \rho U A g \left[ \frac{U^2}{2g}(1 + k) - h \right]$$

$$U_{\text{opt}} = \sqrt{\frac{2gh}{3(1 + k)}}$$
In the water flow system shown, reservoir $B$ has variable elevation, $x$. Determine the water level in reservoir $B$ so that no water flows into or out of that reservoir. The speed in the 12 in diameter pipe is 10 ft/sec. Assume the pipes are constructed of cast iron and that the entrances are sharp-edged.

Answer(s):
97.7 ft
Consider the process of donating blood. Blood flows from a vein in which the pressure is greater than atmospheric, through a long small-diameter tube, and into a plastic bag that is essentially at atmospheric pressure. Based on fluid mechanics principles, estimate the amount of time it takes to donate a pint of blood. List all assumptions and show calculations.

*Answer(s):*

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Consider a flow nozzle installation in a pipe. Apply the basic equations to the control volume indicated, to show that the permanent head loss across the meter can be expressed in dimensionless form, as the head loss coefficient,

\[ C_l = \frac{p_1 - p_3}{p_2 - p_1} = \frac{1 - A_2/A_1}{1 + A_2/A_1} \]

Plot, \( C_l \), as a function of diameter ratio, \( D_2/D_1 \).

Answer(s):

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The turbine shown in the figure develops 400 kW. Determine the volumetric flow rate if:
   a. head losses are negligible
   b. head loss due to friction in the pipe is considered.
Assume $f = 0.02$. Discuss your results. Neglect minor losses.

Answer(s):
   a. 14.4 m$^3$/s or 2.1 m$^3$/s
   b. no solution exists
A hydraulic jack supports a load of 20,000 lbf. The following data are given:

- Diameter of piston: 4.0 in
- Radial clearance between piston and cylinder: 0.002 in
- Length of piston: 4.8 in

Estimate the rate of leakage of hydraulic fluid past the piston, assuming the fluid is SAE 30 oil at 80°F.

*Answer(s):*
A hypodermic needle, with an inside diameter of 0.1 mm and a length of 25 mm is used to inject saline solution with a dynamic viscosity five times that of water. The plunger diameter is 10 mm and the maximum force that can be exerted by a thumb on the plunger is 45 N. Estimate the volume flow rate of saline that can be produced.

$\text{Answer(s):}$

$Q = 1.13 \times 10^{-8} \text{ m}^3/\text{s} = 11.3 \text{ mm}^3/\text{s}$
The average flow speed in a constant-diameter section of the Alaskan pipeline is 8.27 ft/s. At the inlet, the pressure is 1200 psig and the elevation is 150 ft; at the outlet, the pressure is 50 psig and the elevation is 375 ft. Calculate the head loss in this section of pipeline.

Answer(s):
\[ H_{L1 \rightarrow 2} = 2940 - 225 \text{ ft} = 2720 \text{ ft} \]
Consider the pipe system shown below in which water (with a density of 1.0E3 kg/m³ and a dynamic viscosity of 1.3E-3 Pa·s) flows from the tank A to tank B. If the required flow rate is 1.0E-2 m³/s, what is the required gage pressure in tank A?

Answer(s): 
\[ p_A = 6.8E5 \text{ Pa} \]
You purchase a cottage at a lake and need to install a pump to feed water to the house. You plan to pump water at night to fill a storage tank you've installed next to the cottage. The pipes and fittings you have chosen to use for the installation are listed in the table below.

a. What is the minimum head rise across a pump that is capable of providing a flow rate of 18.93 liters per minute (= 5 gpm) of water to the tank?

b. What power should be supplied to the pump assuming the pump efficiency is 65%.

**System Component** | **Amount**
--- | ---
straight, smooth plastic pipe, 5.08 cm (= 2 in.) diameter | 28.96 m (=95 ft)
re-entrant inlet | 1
regular 90° flanged elbow | 10
union | 8
fully open globe valve | 1
fully open gate valve | 4

**Answer(s):**

\( H_{S,1-2} = 15.28 \text{ m} \)

\( W_{\text{supply}} = 72.7 \text{ W} \)
Water at 70 °F flows steadily through a venturi. The pressure upstream from the throat is 5 psig. The throat area is 0.025 ft² and the upstream area is 0.1 ft². Estimate the maximum flow rate this device can handle without cavitation.

Answer(s):
1.37 ft³/s
In the five-pipe horizontal network shown in the figure, assume that all pipes have a friction factor $f=0.025$. For the given inlet and exit flow rate of 2 ft$^3$/s of water at 20 °C, determine the flow rate and direction in all pipes. If $p_A=120$ lb/in$^2$ (gage), determine the pressures at points B, C, and D.

**Answer(s):**

- $Q_{AB} = 1.19 \times 10^0$ ft$^3$/s
- $Q_{AC} = 8.13 \times 10^{-1}$ ft$^3$/s
- $Q_{BC} = 9.90 \times 10^{-1}$ ft$^3$/s
- $Q_{CD} = 1.80 \times 10^0$ ft$^3$/s
- $Q_{BD} = 1.97 \times 10^{-1}$ ft$^3$/s
- $p_B = 1.08 \times 10^2$ psig
- $p_C = 1.03 \times 10^2$ psig
- $p_D = 7.57 \times 10^1$ psig
Two water reservoirs are connected by galvanized iron pipes. Assume \( D_A = 75 \text{ mm} \), \( D_B = 50 \text{ mm} \), and \( h = 10.5 \text{ m} \). The length of both pipes is 100 m. Compare the head losses in pipes \( A \) and \( B \). Compute the volume flow rate in each pipe.

**Answer(s):**

- The head loss in each pipe is the same and equal to 10.5 m.

\[
Q_A = \frac{\pi D_A^2}{4} = 1.04 \times 10^{-2} \text{ m}^3/\text{s}
\]

\[
Q_B = \frac{\pi D_B^2}{4} = 3.65 \times 10^{-3} \text{ m}^3/\text{s}
\]