5. Pipeline Head Loss

Contents

Course Website

http://54.243.252.9/ce-3372-webroot/

Readings

Textbook

Gupta, R.S., 2017. Hydrology and Hydraulic Systems, pp 633-652

Additional Readings

2. Nickerson G. 2008. "Water Distribution Systems" in Land Development Handbook, Ed. S.O. Dewberry, Dewberry Inc., McGraw-Hill
3. Roberson, J.A., Cassidy, J.J., and Chaudry, M.H. (1988) Closed Conduits in "Hydraulic Engineering." Houghton Mifflin Co. pp. 240-310
4. Chin, D. (2006). pp. 10-26 in "Water Resources Engineering, 2 ed." Prentice Hall, Inc.
5. Cleveland, T. G. (2020) *Water Systems Design Notes (Pipe Hydraulics Part 1) to accompany CE-3372*, Department of Civil, Environmental, and Construction Engineering, Whitacre College of Engineering.
6. Cleveland, T. G. (2020) *Water Systems Design Notes (Pipe Hydraulics Part 2) to accompany CE-3372*, Department of Civil, Environmental, and Construction Engineering, Whitacre College of Engineering.
7. Cleveland, T. G. (2020) *Water Systems Design Notes (Pipe Hydraulics Part 3) to accompany CE-3372*, Department of Civil, Environmental, and Construction Engineering, Whitacre College of Engineering.

Videos

1. none

Lesson Outline

1. topic1
2. topic2
3. topic3

Energy and Friction

Water moves from higher to lower energy

- Path of least resistance

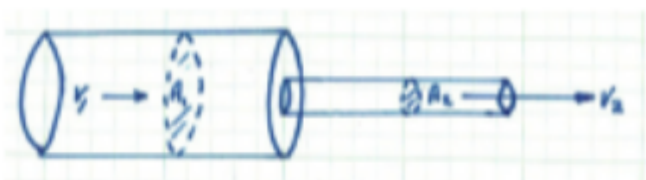
- Head is energy per unit weight of a fluid
- Pumps are used to add energy to move water to a higher elevation or over a barrier
- Gravity flow: Change in elevation provides the required energy
- Pressure flow: Change in pressure provides the required energy

Flowing water encounters friction/resistance; hence there is loss of energy along a flow path. The mean section velocity is related to cross sectional flow area and volumetric discharge as:

$$\bar{V} = \frac{Q}{A}$$

Continunity at Different Sections

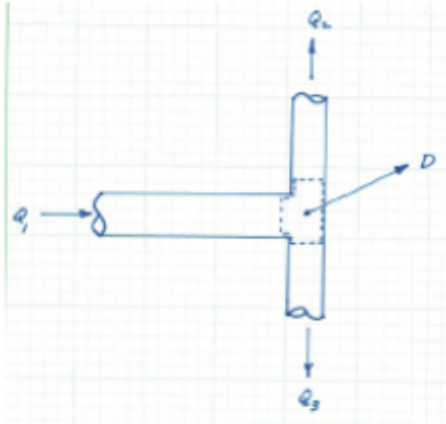
The continunity (conservation of mass) across two cross-sections of pipe as shown



is $A_1V_1 = A_2V_2$. It is a statement that discharge is the same in each portion of pipe unless there is a loss somewhere.

Continunity at Junctions

A junction is a location where two or more conduits join together. By convention (collective agreement) flow into a junction is a positive value, flow out from a junction is a negative value. External demands are conceptualized as flow **out** of the junction. While uncommon,flow injected into a junction it would be treated as a negative demand (in most computation tools!)



The continunity equation for the junction depicted above is $Q_1 - Q_2 - Q_3 - D = 0$ An easy way to remember continunity is $In - Out = 0$

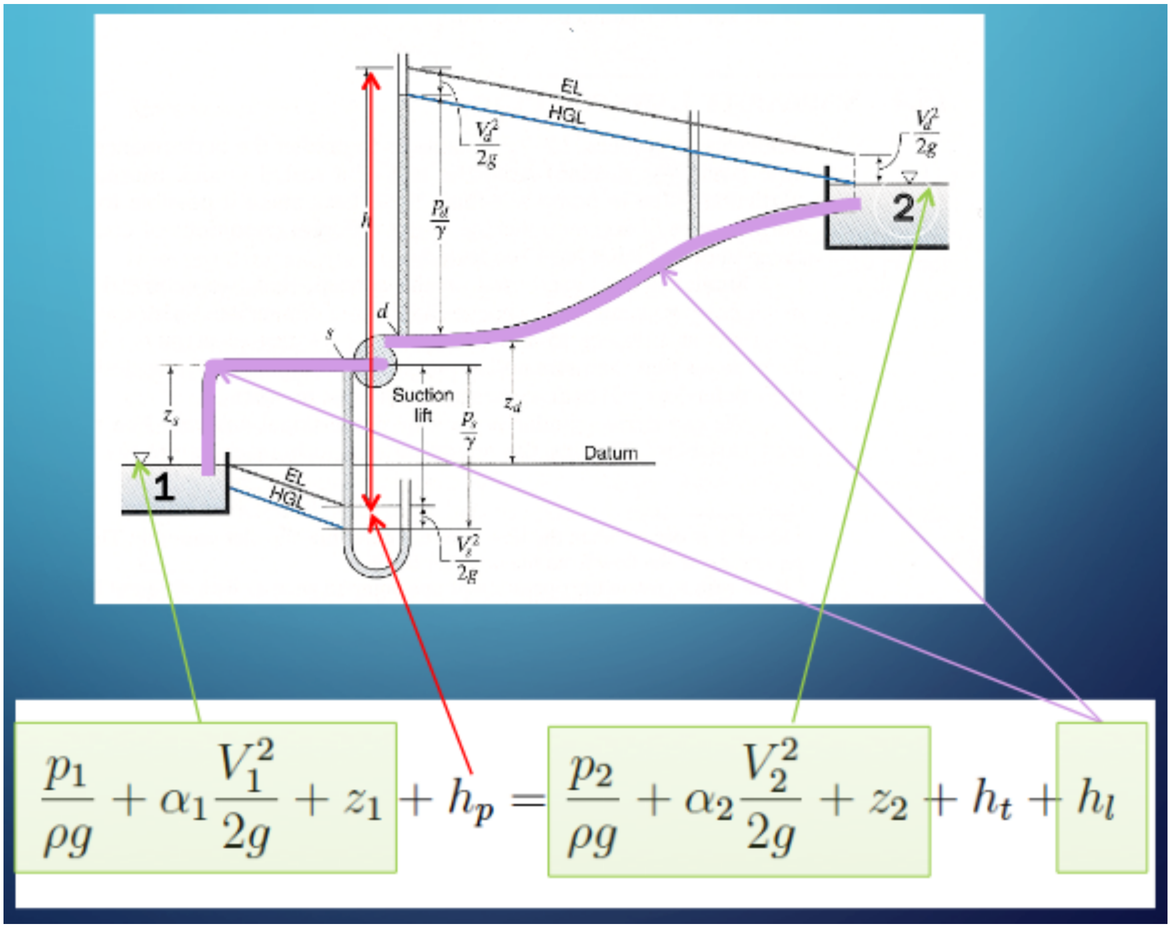
Energy Equation

The energy equation (modified bernoulli equation) relates the total dynamic head at two points in a system, accounting for frictional losses and any added head from a pump.

$$\frac{p_1}{\rho g} + \alpha_1 \frac{V_1^2}{2g} + z_1 + h_p = \frac{p_2}{\rho g} + \alpha_2 \frac{V_2^2}{2g} + z_2 + h_t + h_l$$

- h_L = head losses (pipe loss + fitting losses)
- h_p = added pump head
- h_t = head loss to a turbine

The parts of the equation are illustrated below



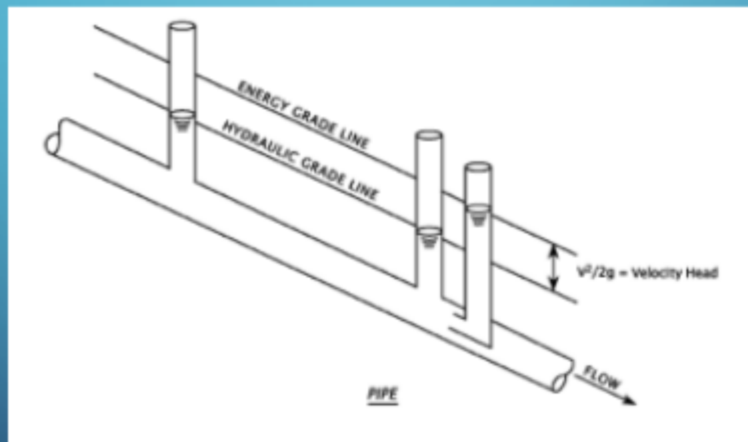
The left-most group is the total energy in the lower reservoir. The pump head provides the energy to lift from the suction side of the pump to the upper reservoir. The water is physically moving upward in the suction pipe, while hydraulically flowing downhill to some minimum at the pump. After the pump supplies additional momentum the water has increased energy to continue its uphill trek to the upper reservoir. The first group to the right of the equal sign is the total energy in the upper reservoir. The last group is the total head loss in the system.

Observe that the HGL and EGL in the system slope downward in the direction of flow; further observe that nearly all groups are dependent on the discharge rate; added head required changes with Q as does the head loss.

The hydraulic grade line (HGL) is depicted below as is the energy grade line (EGL)

HYDRAULIC GRADE LINE

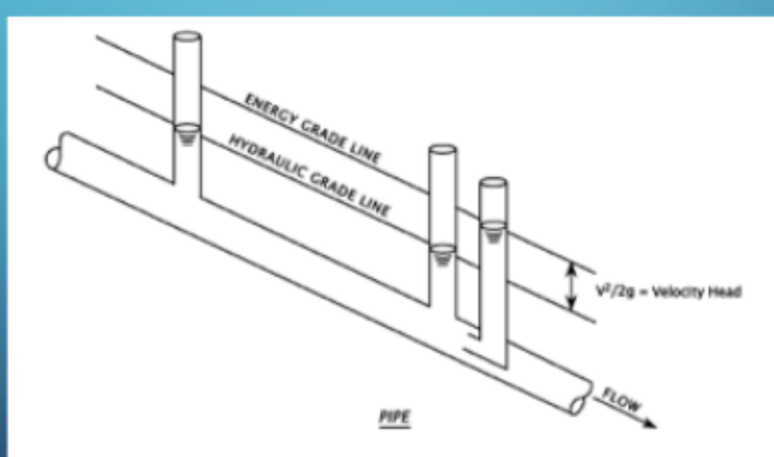
- HGL is a line that represents the surface/profile of water flowing in partially full pipe



- If pipe is under pressure, flowing full the HGL rises to where a free surface would exist if there were a piezometer installed in the pipeline

ENERGY GRADE LINE

- EGL is a line that represents the elevation of energy head of water flowing in a conduit. It is the sum of the elevation, pressure, and velocity head at a location



- Drawn above HGL at a distance equal to the velocity head

We can combine continunity and energy to explain/predic common hydraulic behavior

Example: Time to Drain a Storage Tank

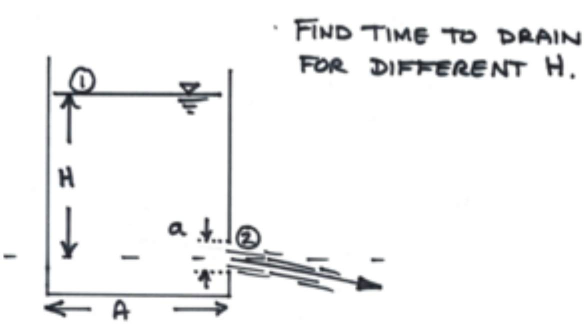
Imagine an ordinary bucket (diameter = 1 foot) with a ½-inch hole drilled at the base of the bucket.

Problem Statement

Develop an equation that estimates time-to-drain for different fill depths (with an unknown drainage coefficient). Use measured data to infer the drainage coefficient.

TIME-TO-DRAIN (SECONDS)				
DEPTH (INCHES)	EXP. 1	EXP. 2	EXP. 3	AVG. TIME
12.00	0.00	0.00	0.00	0.00
9.00	21.97	20.97	21.39	21.44
6.38	42.57	42.47	44.39	43.14
3.50	70.57	69.57	69.59	69.91
0.00	128.57	128.22	126.75	127.85

Sketch Situation; List Known Values



The known values in this case are the tank area A from its given diameter, the outlet area a from its given diameter, and the starting depth H.

List Unknown Values

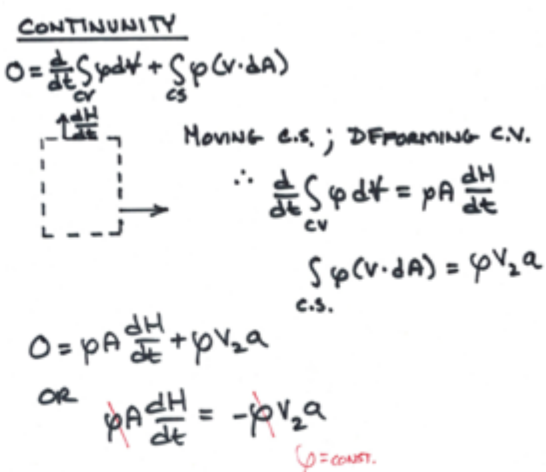
In this case the time to drain and the numerical value of a drainage coefficient that relates the constriction of the jet at the outlet. We can keep it as an unknown variable and use the observations to find a numerical value for this particular bucket.

Governing Principles

- Conservation of mass (Continunity)
- Conservation of energy (Energy equation)

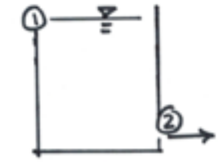
Solution

First use continunity:



Then use energy:

ENERGY



$$\cancel{\frac{p_1}{\gamma}} + \cancel{\frac{V_1^2}{2g}} + z_1 = \cancel{\frac{p_2}{\gamma}} + \frac{V_2^2}{2g} + \cancel{z_2} + \cancel{h_L}$$

= 0 gage   At free surface, small.   = 0 gage   0 (the datum)

Assume can be neglected; will adjust coefficient of discharge later to account for h_L

$$z_1 = \frac{V_2^2}{2g}$$

But $z_1 = H$ (same entity, different name)

$$H = \frac{V_2^2}{2g}$$

Add a discharge coefficient (C_d), won't worry about its value just yet.

$$H = \frac{1}{C_d^2}\frac{V_2^2}{2g}$$

Now apply analysis (that Calculus stuff!)

Now isolate V

$$C_d^2\, 2gH = V_2^2$$

$$V_2 = C_d\sqrt{2g}\sqrt{H}$$

← Wrote this way for upcoming calculus!

Substitute into continuity

$$A\frac{dH}{dt} = -a\,C_d\sqrt{2g}\sqrt{H}$$

Seperate & integrate

$$\text{Ⓐ}\quad \frac{A}{a}\frac{dH}{dt} = -C_d\sqrt{2g}\sqrt{H}$$

Algebra

$$\text{Ⓑ}\quad \frac{A}{a}\frac{dH}{\sqrt{H}} = -C_d\sqrt{2g}\,t$$

Use this form!

$$\text{Ⓒ}\quad \frac{dH}{\sqrt{H}} = \underbrace{-C_d\sqrt{2g}\frac{a}{A}}_{K}\,t$$

Continue to tidy up the equation

$$\frac{dH}{\sqrt{H}} = -C_d K dt$$

$$\int \frac{dH}{\sqrt{H}} = -C_d K \int dt$$

CONSTANT OF INTEGRATION

$$2H^{1/2} = -C_d K t + C$$

EVALUATE AT $t=0$

$$2H_o^{1/2} = C$$

INSERT INTO EQUATION

$$2H^{1/2} = -C_d K t + 2H_o^{1/2}$$

DIVIDE BY 2

$$H^{1/2} = -\frac{C_d K}{2} t + H_o^{1/2}$$

$$H = \left[-\frac{C_d K}{2} t + H_o^{1/2}\right]^2$$

THIS IS OUR DRAINAGE MOD

NOW WE NEED TO BUILD A TOOL

Now we can construct a tool using Computational Thinking (ENGR-1330) methods

```
def HofT(time,Cd,Ho,D,d,g): #create our depth vs time function
    import math
    A = 0.25*math.pi*D**2
    a = 0.25*math.pi*d**2
    K = math.sqrt(2*g)*(a/A)
    HofT = (math.sqrt(Ho)-time*Cd*K/2)**2 # if inner part is <0, then will t
    return(HofT)
```

```
# now a quick test
Ho = 1.0 # one foot depth
D  = 1.0 # one foot diameter
d  = 0.042 # 1/2 inch diameter (in feet)
g  = 32.2 # grabity in US unitz
Cd = 1
time = 139
print("Depth Remain at ",time," seconds is ",round(HofT(time,Cd,Ho,D,d,g),3)
```

```
Depth Remain at  139  seconds is  0.0  feet
```

Now put the function into a repetition structure and use trial-and-error to find a good value for Cd. The goal is for remaining depth to be zero for all cases.

```
D  = 1.0 # one foot diameter
d  = 0.042 # 1/2 inch diameter (in feet)
g  = 32.2 # grabity in US unitz
Cd = 1.125    # Use 2, 1.5, 1.25, 1.125 will see values go up then down towa
Ho = [1.00,0.75,0.53,0.29,0.00] # table of observed depths
time = [127.85,106.41,84.71,57.94,0.00] # table of observed times
how_many = len(Ho)
print("For Cd = ", Cd)
for i in range(how_many):
    print("Depth Remain at ",time[i]," seconds is ",round(HofT(time[i],Cd,Ho
```

```
For Cd =  1.125
Depth Remain at  127.85  seconds is  0.0  feet
Depth Remain at  106.41  seconds is  0.0  feet
Depth Remain at  84.71  seconds is  0.003  feet
Depth Remain at  57.94  seconds is  0.006  feet
Depth Remain at  0.0  seconds is  0.0  feet
```

The example illustrates the combination of analysis and computation to find a discharge coefficient for a cylindrical tank. These kind of problems are especially fun when the tank geometry is weird and we normally use:

- Storage-Elevation or Depth-Area tables.
- Finite-difference type computations (rather than analytical functions)

Head Loss Models (for losses in closed conduits)

Darcy-Weisbach

The Darcy-Weisbach frictional head-loss model for pipe flow is

$$h_f = f\frac{L}{D}\frac{V^2}{2g}$$

Frictional loss proportional to:

- Length

- Velocity^2

Inversely proportional to:

- Cross sectional area

Loss coefficient (f) depends on

- Reynolds number (fluid and flow properties)
- Roughness height (pipe material properties)

Reynolds' (Re_d) Number

$$Re_d = \frac{\rho V D}{\mu} = \frac{VD}{\nu}$$

Find viscosity as function of temperature from table look-up at http://54.243.252.9/toolbox/fluidmechanics/WaterPropertiesUS/WaterPropertiesUS.html or http://54.243.252.9/toolbox/fluidmechanics/WaterPropertiesSI/WaterPropertiesSI.html or other source.

Darcy-Weisbach "f" Factor

The friction factor is determined from a Moody Chart or Colebrook-White or Jain equation like:

$$f = \frac{0.25}{[log10(\frac{k_s}{3.7D} + \frac{5.74}{Re^{0.9}})]^2}$$

A web-application with a roughness height database is http://54.243.252.9/toolbox/Databases/RoughnessHeight/RoughnessHeight.html

A web-application to compute friction factor given Re and material properties (k_s) is http://54.243.252.9/toolbox/pipehydraulics/FrictionFactor/FrictionFactor.html

Using the D-W model

To compute headloss is straightforward, first organize your data:

1. Material type, lookup roughness height at http://54.243.252.9/cgi-bin/Databases/RoughnessHeight/RoughnessHeight.py or another source. Remember to cite the source.
2. Viscosity at desired operating temperature, lookup at http://54.243.252.9/toolbox/fluidmechanics/WaterPropertiesUS/WaterPropertiesUS.html or http://54.243.252.9/toolbox/fluidmechanics/WaterPropertiesSI/WaterPropertiesSI.html or another source. Remember to cite the source.
3. Use the pipe diameter and desired flowrate to compute a mean section velocity.
4. Compute the Reynolds number; use the equation or http://54.243.252.9/toolbox/fluidmechanics/ReynoldsNumber/ReynoldsNumber.html
5. Compute the friction factor; use the Moody Chart or Jain equation or http://54.243.252.9/toolbox/pipehydraulics/FrictionFactor/FrictionFactor.html
6. Finally compute the head loss as $h_f = f \frac{L}{D} \frac{V^2}{2g}$

Hazen-Williams

The Hazen-Williams head loss model is for water only, while a bit contrived it is used in the USA extensively.

$$h_f = 3.02 \ L \ D^{-1.167} (\frac{V}{C_h})^{1.85}$$

The model expresses frictional loss

- proportional to Length
- proportional to Velocity^(1.8)
- Inversely proportional to cross section area (as hydraulic radius)

The Loss coefficient (C_h) depends on

- Pipe material, finish, and age

The model should be restricted to:

- Turbulent flow only (Re>4000)
- WATER ONLY!

The discharge form for a circular conduit (aka pipe) is

$$h_f = 3.02\ L\ D^{-1.167}(\frac{4Q}{\pi D^2 C_h})^{1.85}$$

The leading constant changes for US Customary and SI Units.

Hazen-Williams “C” Factor

These are generally tabulated and you can look up values on the internet.

Table 3: Hazen-Williams Coefficients for Different Materials.

Material	C_h	Material	C_h
ABS - Acrylonite Butadiene Styrene	130	Aluminum	130 - 150
Asbestos Cement	140	Asphalt Lining	130 - 140
Brass	130 - 140	Brick sewer	90 - 100
Cast-Iron - new unlined (CIP)	130	Cast-Iron 10 years old	107 - 113
Cast-Iron 20 years old	89 - 100	Cast-Iron 30 years old	75 - 90
Cast-Iron 40 years old	64-83	Cast-Iron, asphalt coated	100
Cast-Iron, cement lined	140	Cast-Iron, bituminous lined	140
Cast-Iron, wrought plain	100	Cast-Iron, seal-coated	120
Cement lining	130 - 140	Concrete	100 - 140
Concrete lined, steel forms	140	Concrete lined, wooden forms	120
Concrete, old	100 - 110	Copper	130 - 140
Corrugated Metal	60	Ductile Iron Pipe (DIP)	140
Ductile Iron, cement lined	120	Fiber	140
Fiber Glass Pipe - FRP	150	Galvanized iron	120
Glass	130	Lead	130 - 140
Metal Pipes - Very to extremely smooth	130 - 140	Plastic	130 - 150
Polyethylene, PE, PEH	140	Polyvinyl chloride, PVC, CPVC	150
Smooth Pipes	140	Steel new unlined	140 - 150
Steel, corrugated	60	Steel, welded and seamless	100
Steel, interior riveted, no projecting rivets	110	Steel, projecting girth and horizontal rivets	100
Steel, vitrified, spiral-riveted	90 - 110	Steel, welded and seamless	100
Tin	130	Vitrified Clay	110
Wrought iron, plain	100	Wooden or Masonry Pipe - Smooth	120
Wood Stave	110 - 120		

Adapted from `http://www.engineeringtoolbox.com/hazen-williams-coefficients-d_798.html`.

Hydraulic Radius

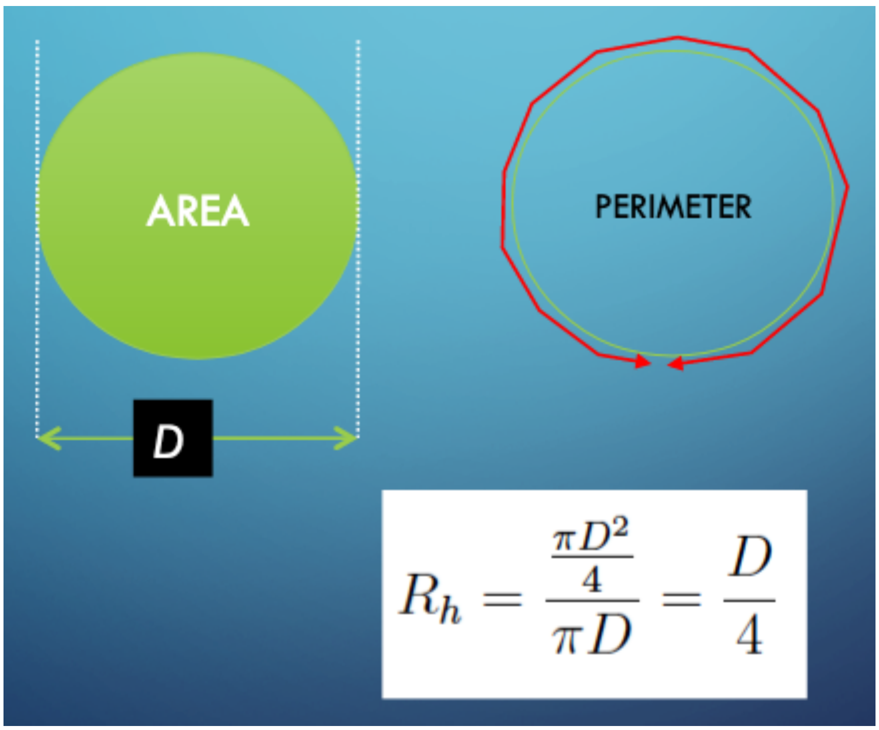
HW is often presented as a velocity equation using the hydraulic radius

$$V = 1.381\ C_h\ R^{0.63}\ S^{0.54}$$

The hydraulic radius is the ratio of cross section flow area to wetted perimeter

$$R_h = \frac{A}{P_w}$$

A full circular pipe has a hydraulic radius equal to 1/4 of the pipe inside diameter



$$R_h = \frac{\frac{\pi D^2}{4}}{\pi D} = \frac{D}{4}$$

Chezy-Mannings

The Chezy-Mannings head loss model, while common in open channel flow and culverts, is not often used on pressure-pipe systems, but it is sometimes applied in large diameter pipes and tunnels (siphons).

$$h_f = L\frac{n^2V^2}{2.22R^{4/3}}$$

Frictional loss proportional to

- Length, Velocity^2
- Inversely proportional to
- Cross section area (as hydraulic radius)

Loss coefficient depends on

- Material, finish

The constant in the denominator changes for US Customary and SI Units.

Mannings "n"

These are generally tabulated; for example:

https://www.engineeringtoolbox.com/mannings-roughness-d_799.html

Fitting (Minor) Losses

Fittings, joints, elbows, inlets, outlets cause additional head loss. Called "minor" loss not because of magnitude, but because they occur over short distances.

$$h_{minor} = K\frac{V^2}{2g}$$

Computing Discharge from Specified Head

Loss

Computational Thinking/Data Science Approach (ENGR 1330)

CT/DS Approach

- State the programming problem
- Known (Inputs)
- Unknown (Outputs)
- Governing Equation(s)
- Test the tool

State the programming problem

Build a tool that takes inputs for the Jain equation and produces an estimate of discharge

Build an interface (notebook) that accepts the inputs, calls the function, and returns the computed discharge

Known (Inputs)

Engineer will specify:

- Diameter, D;
- Length of pipe, L;
- Roughness height, e;
- Viscosity, ν;
- Gravitational acceleration constant, g;
- Head loss

Unknown (Outputs)

The tool will compute and report Discharge, Q.

Governing Equation(s)

A compact form of the equation to be evaluated is

$$Q = -0.965D^2\sqrt{\frac{gDh_f}{L}}ln(\frac{k_s}{3.7D} + \frac{1.78\nu}{D\sqrt{\frac{gDh_f}{L}}})$$

```
# #######prototype function for computation engine ########################
# Define the prototype function
from math import log,sqrt
def jainQ(pipe_diameter,pipe_length,roughness,viscosity,grabity,head_loss):
    egl_slope = head_loss/pipe_length
    t1 = sqrt(grabity*pipe_diameter*egl_slope)
    t2 = roughness/(3.7*pipe_diameter)
    t3 = 1.78*viscosity
    jainQ = (-0.965*pipe_diameter**2)*t1*log(t2 + t3/(pipe_diameter*t1))
    return jainQ
```

Build and Test the tool

To build and test the tool, we have a couple of additional requirements:

- computation engine (above)
- interface engine (to get inputs to send to the computation engine)
- output engine (to actually run the computations, and present outputs)

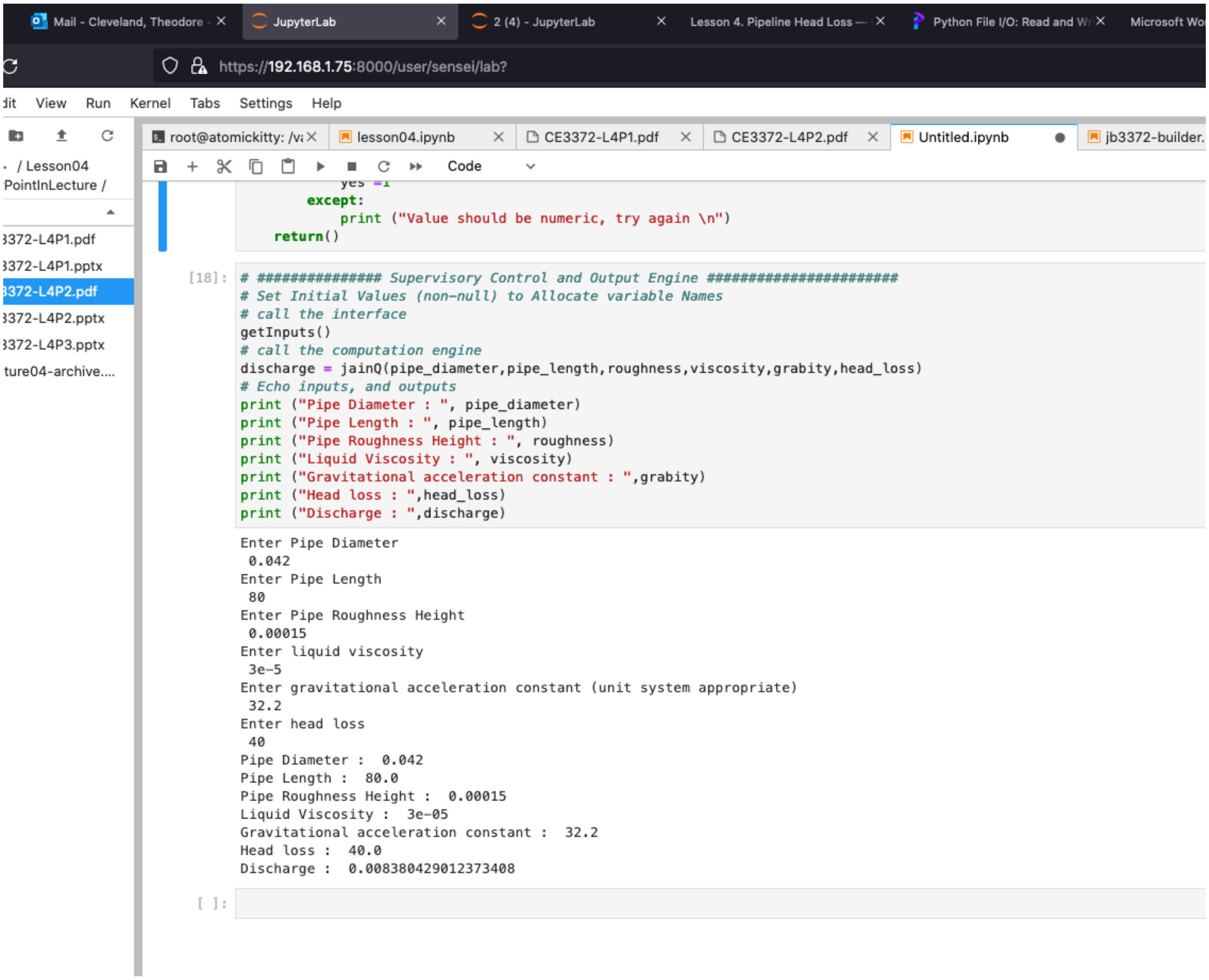
These added parts appear below

```
# ############ Interface engine #########################
def getInputs():
    global pipe_diameter,pipe_length,roughness,viscosity,grabity,head_loss
# Get pipe diameter, use a simple error trap
    yes=0
    while yes == 0:
        xnow = input("Enter Pipe Diameter \n")
        try:
            pipe_diameter = float(xnow)
            yes =1
        except:
            print ("Value should be numeric, try again \n")
# Get pipe length, use a simple error trap
    yes=0
    while yes == 0:
        xnow = input("Enter Pipe Length \n")
        try:
            pipe_length = float(xnow)
            yes =1
        except:
            print ("Value should be numeric, try again \n")
# Get roughness, use a simple error trap
    yes=0
    while yes == 0:
        xnow = input("Enter Pipe Roughness Height \n")
        try:
            roughness = float(xnow)
            yes =1
        except:
            print ("Value should be numeric, try again \n")
# Get viscosity, use a simple error trap
    yes=0
    while yes == 0:
        xnow = input("Enter liquid viscosity \n")
        try:
            viscosity = float(xnow)
            yes =1
        except:
            print ("Value should be numeric, try again \n")
# Get grabity, use a simple error trap
    yes=0
    while yes == 0:
        xnow = input("Enter gravitational acceleration constant (unit system
        try:
            grabity = float(xnow)
            yes =1
        except:
            print ("Value should be numeric, try again \n")
# Get head loss, use a simple error trap
    yes=0
    while yes == 0:
        xnow = input("Enter head loss \n")
        try:
```

```
            head_loss = float(xnow)
            yes =1
        except:
            print ("Value should be numeric, try again \n")
    return()
```

```
# ############### Supervisory Control and Output Engine ###################
getInputs() # call the interface
discharge = jainQ(pipe_diameter,pipe_length,roughness,viscosity,grabity,head
# output
print ("Pipe Diameter : ", pipe_diameter)
print ("Pipe Length : ", pipe_length)
print ("Pipe Roughness Height : ", roughness)
print ("Liquid Viscosity : ", viscosity)
print ("Gravitational acceleration constant : ",grabity)
print ("Head loss : ",head_loss)
print ("Discharge : ",discharge)
```

A cut and paste the code of the code above into a Jupyter Notebook should produce output like:



Refine the Tool for Generalization

The refinement step would wrap the above script into a single function/notebook for simple use/reuse. If we save to a single file, we can access the script as we wish (using a JupyterLab magic function).

> Or, we can put the script onto a server and access via a web interface as is done at http://54.243.252.9/toolbox/pipehydraulics/QGivenHeadLoss/QGivenHeadLoss.html The server-side python code is shown below as is the interface HTML

Note

The server-side code that performs the functions of input interface is listed below. On an apache web server the code would go in the webroot `/var/www/html/path-to-html/`

```
<!DOCTYPE html PUBLIC >
<html><head><title>Discharge Given Head Loss</title></head>
<link rel = "stylesheet" type = "text/css" href = "styles.css" >
<body>
<h1> Discharge in Pressure Conduit Given Head Loss </h1>

<p> Computes Discharge given Diameter, Material, and Head Loss using
<img src = "./QGivenHeadLoss.gif"  > <br/>
<p>
  D = Pipe diameter (in feet or meters) <br/>
  g = Gravitational acceleration constant (32.2 ft/s^2 or 9.8 m/s^2)
 hl = Head loss (in feet or meters) <br/>
  L = Pipe length (feet or meters) <br/>
 ks = Equivalent sand roughness height (a material property; in feet
  v = Kinematic viscosity (in feet^2/second or meter^2/second)  <br/

<br/>
Notes: <br/>
Swamee and Jain, A. K., 1976. Explicit equations for pipe-flow probl
ASCE J. of Hyd. Div., 102(HY5) pp. 657-664 <br/><br/>

</p>

<form method ="POST"
      action = "http://54.243.252.9/cgi-bin/pipehydraulics/QGivenHea


Enter Value for Diameter (D in feet or meters) : <br/>
<input type = "text" name = "diameter"><br/>

Enter Value for Gravitational acceleration (g in feet/s^2 or meters/
<input type = "text" name = "gravity"><br/>

Enter Value for Head loss (hl in feet or meters) : <br/>
<input type = "text" name = "headloss"><br/>

Enter Value for Pipe Length (L in feet or meters) : <br/>
<input type = "text" name = "length"><br/>

Enter Value for Roughness height (ks in feet or meters): <br/>
<input type = "text" name = "roughness"><br/>

Enter Value for Kinematic viscosity (v in feet^2/second or meter^2/s
<input type = "text" name = "kinematic"><br/>

<input type = "submit">
</form>
</body>
</html>
```

Note

The server-side code that performs the functions of computation and output formatting is listed below. On an apache web server the code would go in cgi-bin, or another directory where you allow execution to occur. On my server this code is located in `/usr/lib/cgi-bin/path-to-script/`

```
#!/usr/bin/python
# QGivenHeadLoss.py
# Computes Discharge given HeadLoss
# Use HMTL POST method
# Use PYTHON language


# Import modules for CGI handling
import cgi, cgitb , time
# Import log function
from math import sqrt,log


# Create instance of FieldStorage
form = cgi.FieldStorage()

# Get inputs from fields
diameter = float(form.getvalue('diameter'))
gravity = float(form.getvalue('gravity'))
headloss = float(form.getvalue('headloss'))
length = float(form.getvalue('length'))
roughness = float(form.getvalue('roughness'))
kinematic = float(form.getvalue('kinematic'))


# Perform arithmetic (assembly language style -- equation a bit too
temp0 = sqrt( gravity*diameter*headloss/length )
temp1 = roughness/(3.7*diameter)
temp2 = 1.784*kinematic
temp3 = diameter*temp0
temp4 = temp1 + temp2/temp3
temp5 = -0.965*diameter**2.0
discharge = temp5 * temp0 * log( temp4 )

# Prepare the output HTML
now = time.strftime("%c")

print "Content-type:text/html\r\n\r\n"
# should have two returns and line feeds
print "<html>"
print "<head>"
print "<title>Discharge given Head Loss  using Jain (1976) using Pyt
print "</head>"
print "<body>"
print "Discharge given Head Loss using Jain (1976) using Python <br/
print "Host Name : 54.243.252.9 (AWS East) <br/>"
print "Run Date : " , now ," <br/> "
print "------ INPUT VALUES ------ <br/> "
print "-- USE CONSISTENT UNITS -- <br/> "
print "   Diameter = ", diameter ," [L] <br/> "
print "          g = ", gravity ," [L]/[T]^2  <br/> "
print "  Head Loss = ", headloss ," [L] <br/> "
```

```
print "  Pipe Length = ", length ," [L] <br/> "
print "  Roughness   = ", roughness ," [L] <br/> "
print "  Kinematic Viscosity = ", kinematic ," [L]^2/[T] <br/> "
print "------ COMPUTED DISCHARGE ----- <br/> "
print " Roughness Ratio = ",roughness/diameter, " <br/> "
# begin debug -- comment out when working OK
#print " temp0 ",temp0, " <br/> "
#print " temp1 ",temp1, " <br/> "
#print " temp2 ",temp2, " <br/> "
#print " temp3 ",temp3, " <br/> "
#print " temp4 ",temp4, " <br/> "
#print " temp5 ",temp5, " <br/> "
# end debugging
print "     Discharge = ", discharge, " [L]^3/[T] <br/>"
print "</body>"
print "</html>"

# end of script
```

Computing Diameter from Specified Discharge

A rearrangement of the previous model can provide a way to estimate diameter to convey a particular discharge.

$$D = 0.66[k_s^{1.25}(\frac{LQ^2}{gh_f})^{4.75} + \nu Q^{9.4}(\frac{L}{gh_f})^{5.2}]^{0.04}$$

applying the same Computational Thinking principles, a similar tool can be built for frequent use, pretty much reusing the same scripts but a different computation engine to solve for diameter. The scripting is left as an exercise.

A web-based version is located at http://54.243.252.9/toolbox/pipehydraulics/DiameterGivenDischarge/DGivenQ.html

End of Section