CE 3372 – Water Systems Design
Exercise Set 4

Purpose: Review and application of head loss models used in water transmission and distribution system analysis

Exercises

1. Equation 1 is the Hazen-Williams discharge formula in US Customary Units.

$$Q = 1.318 C_h A R^{0.63} S^{0.54} \quad (1)$$

where;
Q is the discharge in ft^3/sec;
A is the cross section area of pipe in ft^2 ($A = \frac{\pi D^2}{4}$; D is the pipe diameter.);
C_h is the Hazen-Williams friction coefficient (depends on pipe roughness);
R is the hydraulic radius in ft; and
S is the slope of the energy grade line ($\frac{h_f}{L}$); L is the length of pipe.

(a) Look up the Hazen-Williams loss coefficient (C_h) for enamel coated, steel pipe and cite your data source.

(b) Estimate the head loss in a 10,000 foot length of 5-foot diameter, enamel coated steel pipe that carries carries 60^{o}F water at a discharge of 295 cubic-feet per second (cfs), using the Hazen-Williams head loss model.

2. Equation 2 is the Hazen-Williams discharge formula in SI Units.

$$Q = 0.849 C_h A R^{0.63} S^{0.54} \quad (2)$$

where;
Q is the discharge in m^3/sec;
A is the cross section area of pipe in m^2 ($A = \frac{\pi D^2}{4}$; D is the pipe diameter.);
C_h is the Hazen-Williams friction coefficient (depends on pipe roughness);
R is the hydraulic radius in m; and
S is the slope of the energy grade line ($\frac{h_f}{L}$); L is the length of pipe.

(a) Look up the Hazen-Williams loss coefficient (C_h) for Acrylonite Butadiene Styrene (ABS) pipe and cite your data source.

(b) Estimate the head loss in a 3,050 meter length of 1.5-meter diameter, ABS pipe that carries carries 20^{o}C water at a discharge of 8.35 cubic-meters per second (cms), using the Hazen-Williams head loss model.

3. Equation 3 is an explicit formula (based on the Darcy-Weisbach head loss model and the Colebrook-White frictional loss equation)for estimating discharge from head loss and material properties (Swamee and Jain, 1976).

$$Q = -2.22D^{5/2} \times \sqrt{gh_f/L} \times [log_{10}(\frac{k_s}{3.7D} + \frac{1.78\nu}{D^{3/2}\sqrt{gh_f/L}})] \quad (3)$$

where;

Q is the discharge in L^3/T;
D is the pipe diameter;
h_f is the head loss in the pipe;
g is the gravitational acceleration constant;
L is the length of pipe;
k_s is the pipe roughness height;
ν is the viscosity of liquid in the pipe;

(a) Find the viscosity for water at 50^{o}F. Cite the source of your value.

(b) Find the sand roughness height of ductile iron pipe. Cite the source of your value.

(c) How deep is a column of water if the pressure at the bottom of the column is 20 psi?

(d) Estimate the discharge in the 3 mile long, 24-inch diameter, ductile iron pipeline connecting points A and B depicted in Figure 1. Point A is 30 feet higher in elevation than point B. The pressure at point B is 20 pounds per square-inch (psi) greater than the pressure at point A.

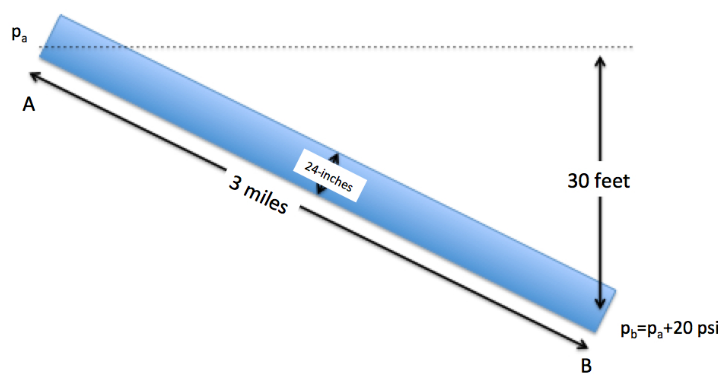

Figure 1: Pipeline Schematic

4. Equation 4 is a formula to estimate the required pipe diameter for a particular discharge, head loss, and roughness (Swamee and Jain, 1976).

$$D = 0.66[k_s^{1.25} \times (\frac{LQ^2}{gh_f})^{4.75} + \nu Q^{9.4} \times (\frac{L}{gh_f})^{5.2}]^{0.04} \tag{4}$$

where;

D is the pipe diameter;
k_s is the pipe roughness height;
L is the length of pipe;
g is the gravitational acceleration constant;
Q is the discharge in L^3/T;
h_f is the head loss in the pipe;
ν is the viscosity of liquid in the pipe;

(a) Find the viscosity for water at 60^oF. Cite the source of your value.

(b) Find the sand roughness height of cast-iron pipe. Cite the source of your value.

(c) Estimate the diameter of a cast-iron pipe needed to carry 60^oF water at a discharge of 10 cubic-feet per second (CFS) between two reservoirs 2 miles apart with an elevation difference between the water surfaces in the two reservoirs of 20 feet as depicted in Figure 2.

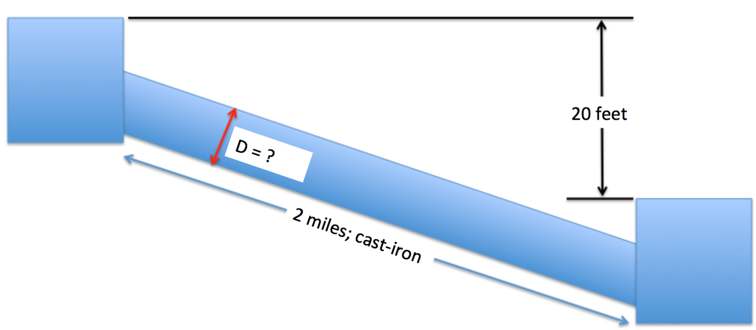

Figure 2: Pipeline connecting two reservoirs

5. Figure 3 is an aerial image of a parallel pipeline system in California.

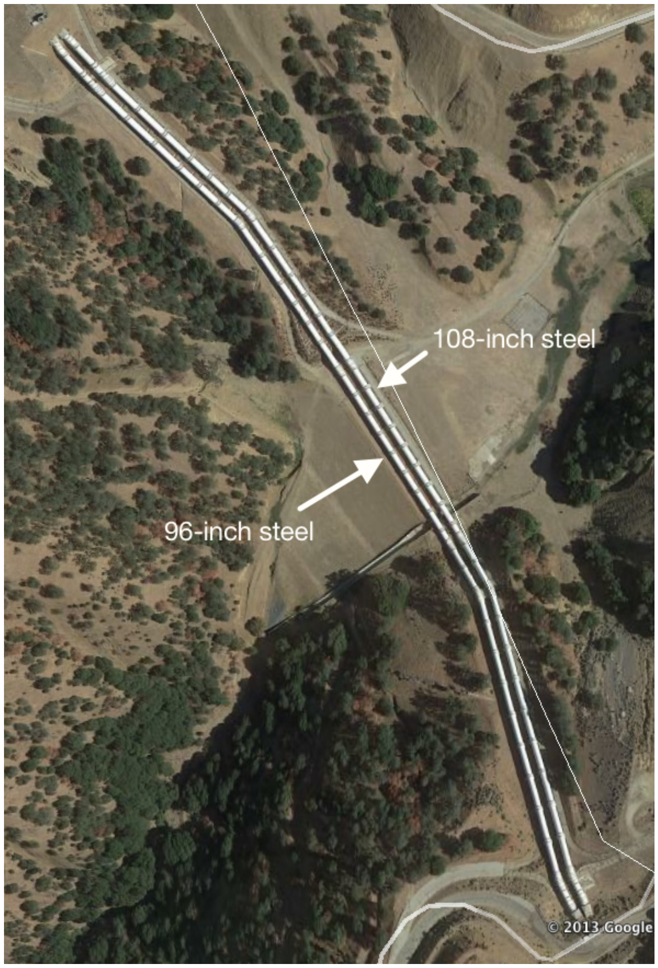

Figure 3: Parallel Pipeline System

The left pipeline is a 96-inch diameter steel pipe, whereas the right pipeline is a 108-inch diameter steel pipe. Water at 50^{o}F has kinematic viscosity of $1.45 \times 10^{-5}\ ft^2/s$. The sand roughness of ductile iron is $1.64 \times 10^{-4}\ ft$. If the head difference for the one-mile long pipelines between the thrust blocks is 120 feet, determine the discharge in each pipe in cubic-feet-per-second.

References

Swamee and Jain, A. K., 1976. Explicit equations for pipe-flow problems. ASCE J. of Hyd. Div., 102(HY5) pp. 657-664

SOLUTION

CE 3372 – Water Systems Design FALL 2017

MEMORANDUM

To:	P. N Guin
From:	P. Olar Bear
Date:	04JAN2024
Subject:	CE 3372 – Water Systems Design, Exercise Set 5.

Purpose

This memorandum presents solutions to several relevant hydraulics problems involving head loss in pipes.

Discussion

The three problems apply the Hazen-Williams equation, Jain Equation for discharge, and Jain Equation for diameter. The results for each problem are presented below; with the actual analysis presented in the attachment.

Problem 1

Problem 1 asks for the conversion of the Hazen-Williams formula into discharge form. The result is

$$h_f = \frac{7.883}{(1.318)^{1.852}} \times \frac{Q}{C_h}^{1.852} \times \frac{L}{D^{4.8707}} \tag{1}$$

The algebra is shown on the attachment pages 1-2.

An estimate of C_h for epoxy-coated steel is 145, from Table 6.1 in `http:\\ncrpb.nic.in`. Using the estimate and the head loss equation above the estimated head loss for the conditions provided is 69.6 feet. The value was checked using a spreadsheet calculator built for Hazen-Williams head loss models (supplied on the class server).

Problem 2

Problem 2 presents the Swamee–Jain equation for discharge given head loss, length, diameter, roughness height, and viscosity, and requests we find values for viscosity at 50^o F and roughness height for iron pipe, determine the equivalent height of a column of water that would produce a pressure of 420 psi and finally determine the volumetric flow rate in a pipeline given elevation and pressure changes (and diameter and material).

The found viscosity values is $\nu = 1.41 \times 10^{-5}$ feet^2/second. The reference used is the water properties database located at `http:\\cleveland1.ddns.net\mytoolbox-server`

The found roughness height is 0.0002 inches. The reference used is `http:\\engineersedge.com\fluid_flow\pipe-roughness.htm`

The equivalent height of a column of water at 20 psi is 46.154 feet. The hydraulic analysis for this equivalent height is shown in the attachments (pg 6).

The computed flow rate in the pipeline is 9.7 cfs. The values are verified by both the online calculator at `http:\\cleveland1.ddns.net\mytoolbox-server` and the spreadsheet calculator used in lecture 5.

Problem 3

Problem 3 presents the Swamee–Jain equation for diameter given head loss, length, discharge, roughness height, and viscosity. The viscosity is $\nu = 1.22 \times 10^{-5}$ feet^2/second. The roughness height selected is 0.0002 inches.

The pipeline connects two reservoirs, 2 miles apart, that have a total head difference of 20 feet. Application of the Swamee–Jain equation for diameter produced an estimate (by-hand) of $D = 1.78$ feet. The value was verified using the online calculator at `http:\\cleveland1.ddns.net\mytoolbox-server`

Concluding Remarks

These problems required analysis and application of principles and tools presented in Lecture 5, Head Loss Models. The problems are all worked by-hand, and verified using online and user-built spreadsheets.

Sincerely,
P. Olar Bear
Icehaus GmBH

Attachment(s):
(1) By-hand analysis for Problem 1 – 3; Including printouts of indicated references, on-line calculators, and user-written spreadsheet programs.

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1a)

$$Q = 1.318\, C_h\, A R^{0.63}\, S^{0.54}$$

$$S = h_f / L \qquad R = \frac{D}{4} \text{ (Pipe is full)}$$

$$Q = 1.318\, C_h \left(\frac{\pi D^2}{4}\right)\left(\frac{D}{4}\right)^{0.63}\left(\frac{h_f}{L}\right)^{0.54}$$

ALGEBRA

$$Q\,(1.318)^{-1}\, C_h^{-1} \left(\frac{\pi D^2}{4}\right)^{-1}\left(\frac{D}{4}\right)^{-0.63} = \left(\frac{h_f}{L}\right)^{0.54}$$

MORE ALGEBRA

$$Q\,(1.318)^{-1}(C_h)^{-1}\left(\frac{\pi D^2}{4}\right)^{-1}\left(\frac{D}{4}\right)^{-0.63} L^{0.54} = h_f^{0.54}$$

NOW RAISE BOTH SIDES BY $\frac{1}{0.54}$

$$Q^{\frac{1}{0.54}}\,(1.318)^{\frac{-1}{0.54}}(C_h)^{\frac{-1}{0.54}}\left(\frac{\pi D^2}{4}\right)^{\frac{-1}{0.54}}\left(\frac{D}{4}\right)^{\frac{-0.63}{0.54}} L = h_f$$

NOW DEAL (EVALUATE) WITH EXPONENTS

$$\frac{1}{0.54} = 1.8518519 \approx 1.852$$

$$Q^{1.852}(1.318)^{-1.852}(C_h)^{-1.852}\left(\frac{\pi D^2}{4}\right)^{-1.852}\left(\frac{D}{4}\right)^{-1.1667} L = h_f$$

ALGEBRA

$$Q^{1.852}(1.318)^{-1.852}(C_h)^{-1.852}\left(\frac{4}{\pi D^2}\right)^{1.852}\left(\frac{4}{D}\right)^{1.1667} L = h_f$$

$4^{1.852} = 12.553$

$4^{1.1667} = \cancel{10.084}\ 5.6399171$

$\pi^{1.852} = 8.3315$

COLLAPSE CONSTANTS

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$$Q^{1.852}(1.318)^{-1.852}(C_h)^{-1.852}\;7.883\left(\frac{1}{D^2}\right)^{1.852}\left(\frac{1}{D}\right)^{1.1667} L = h_f$$

ALGEBRA

$$\cancel{Q}^{1.852}\cancel{(1.318)}^{-1.852}\cancel{(C_h)}^{-1.852}\;\cancel{7.883}\;\frac{1}{D^{4.8707}}\,L = h_f$$

NOW COLLAPSE AGAIN

$$h_f = \frac{7.883}{(1.318)^{1.852}}\cdot\left(\frac{Q}{C_h}\right)^{1.852}\frac{L}{D^{4.8707}}$$

CHECK INTERNET ; THIS IS THE U.S. CUSTOMARY CONSTANT

SI CONSTANT IS 0.849

USE ABOVE TO BUILD CALCULATOR

(WILL ALSO DO BY-HAND NEXT SHEET)

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1b) $C_h = 145$

From (http:\\ncrpb.nic.in/NCRBP%20ADB-TA%207055/repository/pdf/clause/table6.1.pdf)

1c)

$$h_f = \underbrace{\frac{7.883}{(1.318)^{1.852}}}_{=\,4.7273} \cdot \underbrace{\left(\frac{295}{145}\right)^{1.852}}_{=\,3.7261} \cdot \underbrace{\frac{(10{,}000)}{(5)^{4.8707}}}_{=\,3.9403}$$

$$= 4.7273 * 3.7261 * 3.9403$$

$$= 69.4 \text{ feet.}$$

(ALSO IS HAZEN-WILLIAMS CALCULATOR THAT IMPLEMENTS ABOVE EQUATION)

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Table 6.1 Hazen - Williams coefficients

Pipe Material	Recommended C Value New Pipes@	Design Purpose
Unlined Metallic Pipes		
Cast Iron, Ductile Iron	130	100
Mild Steel	140	100
Galvanized Iron above 50 mm dia. #	120	100
Galvanized Iron 50 mm dia and below used for house service connections. #	120	55
Centrifugally Lined Metallic		
Cast Iron, Ductile Iron and Mild Steel Pipes lined with cement mortar or Epoxy		
Upto 12000 mm dia	140	140
Above 1200	145	145
Projection Methose Cement Mortar Lined Metallic Pipes		
Car Cast Iron, Ductile Iron and Mild Steel Pipes	130*	110**
Non Metallic Pipes		
RCC Spun Concrete		
Prestressed Concrete		
Up to 1200 mm dia	140	140
Above 1200 mm dia	145	145
Asbestos Cement	150	140
PVC, GRP and other Plastic Pipes.	150	145

Notes:

@ The C values for new pipes included in the Table 6.1 are for determining the acceptability of surface finish of new pipelines. The user agency may specify that flow test may be consucted for determining the C value of laid pipelines.

The quality of galvanizing should be in accordance with the relevant standards to ensure resistance to corrosion through out its design life.

* For pipes of diameter 500 mm and above; the range of C values may be from 90 to 125 for pipes less than 500 mm.

** In the absence of specific data, this value is recommended. However, in case authentic field data is available, higher values upto 130 may be adopted.

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	A	B	C	D	E	F	G	H
1	Hazen-Williams Head Loss Calculator							
2		INPUTS						
3	Unit System	US	<= Pull Down Menu					
4	Loss Coefficient	145	Table Lookup =>	http://www.engineeringtoolbox.com/hazen-williams-coefficients-d_798.html				
5	Diameter	5	feet					
6	Length	10000	feet					
7	Discharge	295	cubic feet per second					
8		INTERMEDIATE CALCULATIONS						
9	k-units	1.318						
10	OUTPUTS							
11	Head Loss	69.41	feet					

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2a) USE ON-LINE TOOL

http:\\cleveland1.ddns.net/cgi-bin/WaterPropertiesUS/
WaterPropertiesUS.py (ATTACHED)

$\nu = 1.41 \cdot 10^{-5}\ ft^2/s$

2b) $k_s = 0.0002$ inches

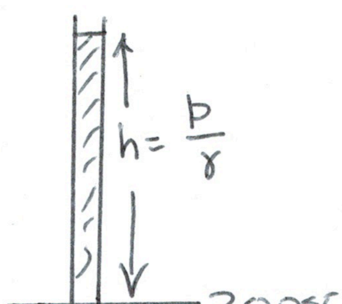
http:\\engineersedge.com/fluid_flow/pipe_roughness.htm
(ATTACHED)

$k_s = \dfrac{0.0002\ \text{inches}}{12\ \text{inches}} = 0.0000167\ ft$

$= 0.0167 \cdot 10^{-3}\ ft$

$= 16.7 \cdot 10^{-6}\ ft$ (16.7 millifeet)

2c)



FIND h

$p = \dfrac{20\ lbf}{in^2} \cdot \dfrac{144\ in^2}{1\ ft^2} = 2880\ lbf/ft^2$

$h = \dfrac{2880\ \frac{lbf}{ft^2}}{62.4\ \frac{lbf}{ft^3}} = 46.154\ ft$

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On-Line Water Property Database (US Customary)

Select Water Temperature (Degrees F)

50 degrees F | Submit

Water Properties (US Customary)
adapted from Table A5 in Elger, Crowe, Roberson 2013. Engineering Fluid Mechanics. Wiley&Sons.

Run Date : Tue Sep 13 16:58:42 2016
------ INPUT VALUES ------
Temperature = 50.0 (degrees F)
------ LOOKUP VALUES -----
Density = 1.94 (slugs/ft^3)
Specific Weight = 62.4 (lbf/ft^3)
Dynamic Viscosity = 2.73e-05 (lbf-s/ft^2)
Kinematic Viscosity = 1.41e-05 (ft^2/s)
Vapor Pressure = 0.178 (lbf/in^2) - absolute

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Pipe Roughness Coefficients Table Charts

Fluid Flow Table of Contents
Hydraulic and Pneumatic Knowledge
Fluid Power Equipment

This table lists the roughness Coefficients of Specific roughness, Hazen-Williams Coefficient and Manning Factor.

Pipe Material Roughness Coefficients

Pipe Material	Specific Roughness Factor, • , mm (in)	Hazen-Williams Coefficient, C	Manning Factor, n
Steel, welded and seamless	0.061 (0.0002)	140	-
Ductile Iron	0.061 (0.0002)	130	-
Ductile Iron, asphalt coated	0.12 (0.0004)	130	0.013
Copper and Brass	0.61 (0.002)	140	0.010
Glass	0.0015 (0.000005)	140	-
Thermoplastics	0.0015 (0.000005)	140	-
Drawn Tubing	0.0015 (0.000005)	-	-

Sources:
Hydraulic Institute, Engineering Data Book.
Various vendor data compiled by SAIC, 1998.

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Related Resources:

- Kinematic Viscosity Equation Application
- Pressure Drop Along Pipe Length
- Fluid Characteristics Chart Table, Density, Vapor Pressure and Kinematic Viscosity
- Hazen-Williams Coefficients Table
- Hazen-Williams Water Pressure Drop
- Head loss in a Pipe (Darcy - Weisback Equation) Calculator

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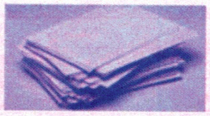

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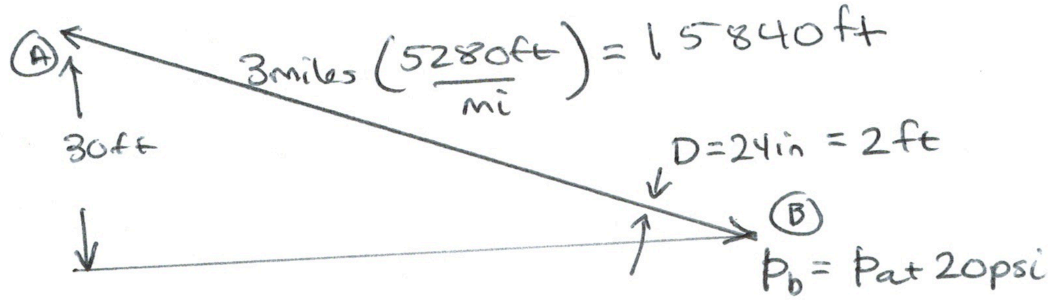
2d)



ENERGY A → B

$$\frac{p_a}{\gamma} + \cancel{\frac{V_a^2}{2g}} + z_a = \frac{p_b}{\gamma} + \cancel{\frac{V_b^2}{2g}} + \underset{0}{\cancel{z_b}} + h_L$$

$$\frac{p_a}{\gamma} - \frac{p_b}{\gamma} + z_a = h_L$$

$$\frac{\cancel{p_a} - \cancel{p_a} - 20psi}{\gamma} + z_a = h_L$$

$$z_a - \frac{20psi}{\gamma} = h_L$$

$$z_a = 30\ ft$$

$$30ft - 46.154ft = -16.154ft$$

PROBABLY FLOWING UPHILL!

IF UPHILL:

$$\frac{p_b}{\gamma} + \cancel{\frac{V_b^2}{2g}} + z_b = \frac{p_a}{\gamma} + \cancel{\frac{V_a^2}{2g}} + z_a + h_L$$

$$\frac{p_a + 20psi}{\gamma} + 0 = \frac{p_a}{\gamma} + 30ft + h_L$$

$$\frac{p_a + 20psi}{\gamma} - \frac{p_a}{\gamma} - 30ft = h_L = 16.154$$

∴ WATER FLOWING RIGHT-TO-LEFT

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USE SWAMEE JAIN TO ESTIMATE Q

$$Q = -2.22\ D^{5/2} \cdot \sqrt{\frac{g h_f}{L}} \left[\log_{10}\left(\frac{k_s}{3.7D} + \frac{1.78\nu}{D^{3/2}\sqrt{\frac{g h_f}{L}}}\right)\right.$$

$$\sqrt{\frac{g h_f}{L}} = \sqrt{\frac{32.2\frac{ft}{s^2}(16.154ft)}{15840 ft}} = 0.1812134$$

$$D^{5/2} = (2)^{5/2} = 5.6568543$$

$$D^{3/2} = (2)^{3/2} = 2.8284271$$

$$\frac{k_s}{3.7D} = \frac{16.7\cdot 10^{-6}}{3.7(2)} = 2.2568\cdot 10^{-6}$$

$$1.78\nu = 1.78(1.41\cdot 10^{-5}) = 2.5098\cdot 10^{-5}$$

$$\log_{10}\left(2.2568\cdot 10^{-6} + 4.8967\cdot 10^{-5}\right) = -4.2905$$

$$D^{5/2}\sqrt{\frac{g h_f}{L}}\log_{10}(\text{—}) = (5.6568543)(0.1812134)(-4.2905)$$
$$= -4.3982$$

$$Q = -2.22(-4.3982) = 9.764\ ft^3/sec$$

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— ONLINE CALCULATOR (ATTACHED)

$Q = 9.77 \, ft^3/s$

— SPREADSHEET CALCULATOR (ATTACHED)

$Q = 9.77 \, ft^3/s$

Discharge in Pressure Conduit Given Head Loss

Computes Discharge given Diameter, Material, and Head Loss using Swamee Jain (1976)

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

D = Pipe diameter (in feet or meters)
g = Gravitational acceleration constant (32.2 ft/s^2 or 9.8 m/s^2)
hl = Head loss (in feet or meters)
L = Pipe length (feet or meters)
ks = Equivalent sand roughness height (a material property; in feet or meters)
v = Kinematic viscosity (in feet^2/second or meter^2/second)

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

Enter Value for Diameter (D in feet or meters) :
2
Enter Value for Gravitational acceleration (g in feet/s^2 or meters/s^2) :
32.2
Enter Value for Head loss (hl in feet or meters) :
16.154
Enter Value for Pipe Length (L in feet or meters) :
15840
Enter Value for Roughness height (ks in feet or meters):
16.7e-6
Enter Value for Kinematic viscosity (v in feet^2/second or meter^2/second):
1.41e-5
Submit

PRESS "SUBMIT"

GET THIS

Friction Factor using Jain (1976) using Python

Run Date : Tue Sep 13 17:19:28 2016
------ INPUT VALUES ------
-- USE CONSISTENT UNITS --
Diameter = 2.0 [L]
g = 32.2 [L]/[T]^2
Head Loss = 16.154 [L]
Pipe Length = 15840.0 [L]
Roughness = 1.67e-05 [L]
Kinematic Viscosity = 1.41e-05 [L]^2/[T]
------ COMPUTED DISCHARGE -----
Roughness Ratio = 8.35e-06
Discharge = 9.77068045167 [L]^3/[T]

	A	B	C	D	E	F	G	H	I
1	Discharge in a Pressure Pipe (SI Units)								
2									
3	INPUTS	VALUE	UNITS						
4	Diameter	2	feet						
5	Gravity	32.2	feet/second^2						
6	Head Loss	16.154	feet						
7	Length	15840	feet						
8	Roughness	1.67E-05	feet						
9	Viscosity	1.41E-05	feet^2/second						
10									
11	RESULT	VALUE	UNITS						
12	Discharge	9.7728	feets^3/second						
13									
14	EXTERNAL DATA SOURCES								
15	http://cleveland1.ddns.net/mytoolbox-server/WaterPropertiesUS/WaterPropertiesUS.html								

=Jain(B4,B7,B8,B5,B9,B6)

SAME AS CLASS,
EXCEPT CHANGED g TO US
AND CHANGED UNITS LABELS

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3a) VISCOSITY AT 60°F
(USE SAME SOURCE
http://cleveland1.ddns.net/cgi-bin/WaterPropertiesUS/WaterProperties.html

$\nu = 1.22 \cdot 10^{-5}\ ft^2/s$

b) https://www.engineersedge.com/fluid_flow/pipe-roughness.htm

$k_s = 0.0002\ in * \frac{1\ ft}{12\ in} = 16.7 \cdot 10^{-6}\ ft$

c) TOTAL HEAD AVAILABLE IS 20 ft $\therefore$ $h_f = 20\ ft$

LENGTH = 5280*2 = 10560 ft

$k_s/D = ?$

$Q = 10\ ft^3/s$

APPLY SWAMEE JAIN FOR D.

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

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NOW EVALUATE PARTS:

$$\frac{LQ^2}{g h_f} = \frac{(10560)(10)^2}{(32.2)(20)} = 1639.7516$$

$$\left(\frac{LQ^2}{g h_f}\right)^{4.75} = \left(1639.7516\right)^{4.75} = 1.8625 \cdot 10^{15}$$

$$\left(\frac{L}{g h_f}\right)^{5.2} = \left[\frac{10560}{(32.2)(20)}\right]^{5.2} = 2074177.2$$

$$\nu Q^{9.4} = \left(1.22 \cdot 10^{-5}\ ft^2/s\right)\left(10\right)^{9.4} = 3.0645 \cdot 10^{4}$$

$$k_s^{1.25} = \left(16.7 \cdot 10^{-6}\right)^{1.25} = 1.0676 \cdot 10^{-6}$$

$$D = 0.66\left[1.0676 \cdot 10^{-6} \times 1.8625 \cdot 10^{15} \times 1 + 3.0645 \cdot 10^{4} \times 2074177.2\right]^{0.04}$$

$$= 1.787\ ft$$

CHECK USING ON-LINE TOOL AT

http://cleveland1.ddns.net/mytoolbox-server/DiameterGivenDischarge/DGivenQ.html

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On-Line Water Property Database (US Customary)

Select Water Temperature (Degrees F)

60 degrees F | Submit — PRESS / GET

Water Properties (US Customary)
adapted from Table A5 in Elger, Crowe, Roberson 2013. Engineering Fluid Mechanics. Wiley&Sons.

Run Date : Tue Sep 13 17:54:35 2016
------ INPUT VALUES ------
Temperature = 60.0 (degrees F)
------ LOOKUP VALUES -----
Density = 1.94 (slugs/ft^3)
Specific Weight = 62.37 (lbf/ft^3)
Dynamic Viscosity = 2.36e-05 (lbf-s/ft^2)
Kinematic Viscosity = 1.22e-05 (ft^2/s)
Vapor Pressure = 0.256 (lbf/in^2) - absolute

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13 Sep 16

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Diameter Given Discharge in a Pressure Pipe

Computes Diameter given Discharge, Material, and Head Loss using Swamee Jain (1976)

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

D = Pipe diameter (in feet or meters)
Q = Discharge (in ft^3/sec or m^3/sec)
g = Gravitational acceleration constant (32.2 ft/s^2 or 9.8 m/s^2)
hl = Head loss (in feet or meters)
L = Pipe length (feet or meters)
ks = Equivalent sand roughness height (a material property; in feet or meters)
v = Kinematic viscosity (in feet^2/second or meter^2/second)

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

Enter Value for Discharge (Q in feet^3/sec or meters^3/sec) :
10
Enter Value for Gravitational acceleration (g in feet/s^2 or meters/s^2) :
32.2
Enter Value for Head loss (hl in feet or meters) :
20
Enter Value for Pipe Length (L in feet or meters) :
10560
Enter Value for Roughness height (ks in feet or meters):
16.7e-6
Enter Value for Kinematic viscosity (v in feet^2/second or meter^2/second):
1.22e-5
Submit

= PRESS

GET

Diameter using Jain (1976) via Python

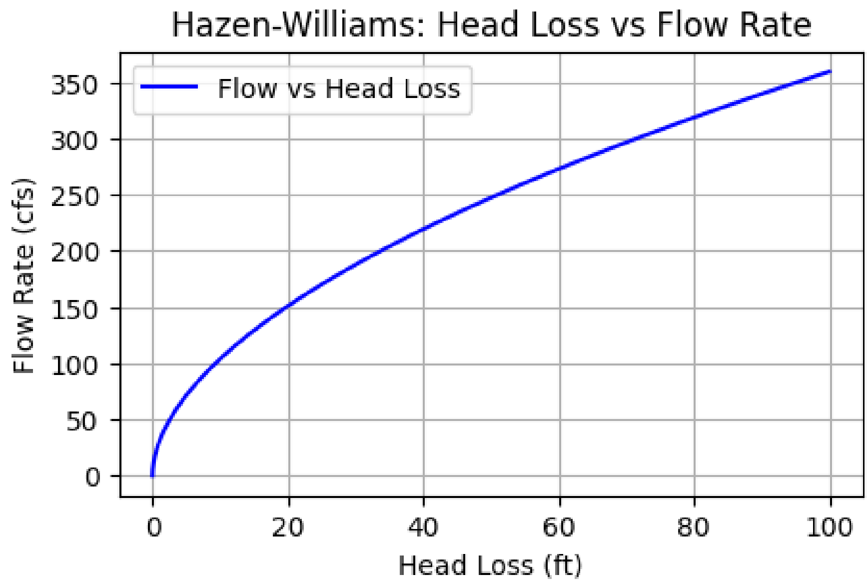
Run Date : Tue Sep 13 18:05:37 2016
------ INPUT VALUES ------
-- USE CONSISTENT UNITS --
Discharge = 10.0 [L]^3/[T]
g = 32.2 [L]/[T]^2
Head Loss = 20.0 [L]
Pipe Length = 10560.0 [L]
Roughness = 1.67e-05 [L]
Kinematic Viscosity = 1.22e-05 [L]^2/[T]
------ COMPUTED DIAMETER -----
Diameter = 1.78734080911 [L]

ES4-P1

February 16, 2025

[66]:

```python
# ES4 Problem 1
# Hazen Williams US Customary
def flowhw(coef, diameter, slope):
    import math
    area = 0.25 * math.pi * diameter**2
    radius = diameter / 4.0
    flowhw = 1.318 * coef * area * (radius**0.63) * (slope**0.54)
    return flowhw

import matplotlib.pyplot as plt
# Parameters
length = 10000  # ft
diameter = 5  # ft
ch = 145  # Hazen-Williams coefficient (Enamel/epoxy look up online)
# Initialize variables
howMany = 10000  # search region
head_loss_values = [0 for i in range(howMany)]
for i in range(howMany):
    head_loss_values[i]=i/100 # search increment
flow_values = []
# Calculate flow rates for each head_loss
for head_loss in head_loss_values:
    slope = head_loss / length
    flow_values.append(flowhw(ch, diameter, slope))
# Plot head_loss vs flow
plt.figure(figsize=(5, 3))
plt.plot(head_loss_values, flow_values, label="Flow vs Head Loss", color="blue")
plt.title("Hazen-Williams: Head Loss vs Flow Rate")
plt.xlabel("Head Loss (ft)")
plt.ylabel("Flow Rate (cfs)")
plt.grid(True)
plt.legend()
plt.show()
```



[67]:
```
def find_closest_index(lst, target):
    return min(range(len(lst)), key=lambda i: abs(lst[i] - target))

# Example Usage
target_value = 295
index = find_closest_index(flow_values, target_value)
print(f"The index of the closest value to {target_value} is {index}.")
print(f"The closest value is {flow_values[index]}.")
print(f"The head loss is {head_loss_values[index]}.")
```

```
The index of the closest value to 295 is 6944.
The closest value is 295.0094006816501.
The head loss is 69.44.
```

[ ]:
```

```

ES4-P2

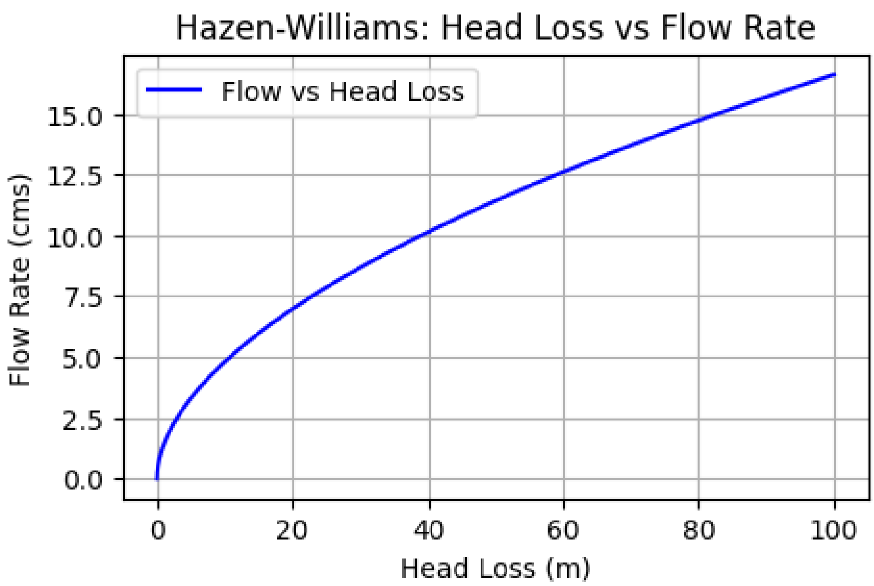
February 16, 2025

[29]:
```
%reset -f
```

[30]:
```
# ES4 Problem 2

# Hazen Williams SI
def flowhw(coef, diameter, slope):
    import math
    area = 0.25 * math.pi * diameter**2
    radius = diameter / 4.0
    flowhw = 0.849 * coef * area * (radius**0.63) * (slope**0.54)
    return flowhw

import matplotlib.pyplot as plt

# Parameters
length = 3050  # m
diameter = 1.5  # m
ch = 130  # Hazen-Williams coefficient (ABS look up online)

# Initialize variables
howMany = 10000  # search region
head_loss_values = [0 for i in range(howMany)]
for i in range(howMany):
    head_loss_values[i]=i/100 # search increment
flow_values = []

# Calculate flow rates for each head_loss
for head_loss in head_loss_values:
    slope = head_loss / length
    flow_values.append(flowhw(ch, diameter, slope))
```

[31]:
```
# Plot head_loss vs flow
plt.figure(figsize=(5, 3))
plt.plot(head_loss_values, flow_values, label="Flow vs Head Loss", color="blue")
plt.title("Hazen-Williams: Head Loss vs Flow Rate")
plt.xlabel("Head Loss (m)")
plt.ylabel("Flow Rate (cms)")
```

```
plt.grid(True)
plt.legend()
plt.show()
```



[32]:
```
def find_closest_index(lst, target):
    return min(range(len(lst)), key=lambda i: abs(lst[i] - target))

# Example Usage
target_value = 8.35
index = find_closest_index(flow_values, target_value)
print(f"The index of the closest value to {target_value} is {index}.")
print(f"The closest value is {flow_values[index]}.")
print(f"The head loss is {head_loss_values[index]}.")
```

```
The index of the closest value to 8.35 is 2800.
The closest value is 8.350386249708711.
The head loss is 28.0.
```

[ ]:
```
```

ES4-P3

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[9]:
```python
# ES4 Problem 3
# Apply Bernoulli's
head_a = 30 + 0 # elevation + pressure (arbitrary)
head_b = 20*144/62.4  # pressure_a + added pressure (given)
#print(head_a)
#print(head_b)
head_loss = head_b - head_a # implies flow uphill
print(head_loss)
```

```
16.153846153846153
```

[16]:
```python
# Swamee-Jain Diameter Discharge

def qJain(diameter,headloss,gravity,length,roughness,viscosity):
    import math
    sqs=math.sqrt(gravity*headloss/length)
    temp1 = roughness/(3.7*diameter)
    temp2 = 1.78*viscosity/(sqs*diameter**(3/2))
    temp3 = math.log10(temp1+temp2)
    qJain = -2.22*(diameter**(5/2))*sqs*temp3
    return qJain

viscosity = 1.41e-05 # table lookup (http://54.243.252.9/cgi-bin/fluidmechanics/
 ↪WaterPropertiesUS/WaterPropertiesUS.py)
roughness = 0.0000167 # table lookup (http://54.243.252.9/cgi-bin/Databases/
 ↪RoughnessHeight/RoughnessHeight.py)
headloss = 16.154 # ft
length = 3*5280 # miles
diameter = 2 # feets
gravity = 32.2
discharge = qJain(diameter,headloss,gravity,length,roughness,viscosity)
print("Discharge = ",round(discharge,3)," CFS ")
```

```
Discharge =  9.764  CFS
```

[ ]:
```python

```

ES4-P4

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[4]:
```python
# ES4 P4

# Swamee Jain Diameter

def dJain(roughness,length,gravity,flow,headloss,viscosity):

    term1 = roughness**(1.25)
    term2 = ((length*flow**2)/(gravity*headloss))**(4.75)
    term3 = viscosity*(flow**(9.4))
    term4 = (length/(gravity*headloss))**(5.2)
    dJain=0.66*((term1*term2+term3*term4)**(0.04))
    return dJain

viscosity = 1.22e-05
roughness = 16.7e-06
gravity = 32.2
discharge = 10.0
length = 2*5280
headloss = 20

print("Diameter = 
 ",round(dJain(roughness,length,gravity,discharge,headloss,viscosity),3)," 
 feet ")
```

```
Diameter =  1.787  feet
```

[ ]:
```python
```

ES4-P5

February 16, 2025

[1]:
```python
# ES4 P5

# Swamee-Jain Diameter Discharge

def qJain(diameter,headloss,gravity,length,roughness,viscosity):
    import math
    sqs=math.sqrt(gravity*headloss/length)
    temp1 = roughness/(3.7*diameter)
    temp2 = 1.78*viscosity/(sqs*diameter**(3/2))
    temp3 = math.log10(temp1+temp2)
    qJain = -2.22*(diameter**(5/2))*sqs*temp3
    return qJain

## Left Pipe
viscosity = 1.45e-05 # given
roughness = 1.64e-04 # given
headloss = 120 # ft
length = 1*5280 # miles
diameter = 96/12 # feets
gravity = 32.2
qleft = qJain(diameter,headloss,gravity,length,roughness,viscosity)
diameter = 108/12 # feets
qright = qJain(diameter,headloss,gravity,length,roughness,viscosity)
print("Left Discharge = ",round(qleft,3)," CFS ")
print("Right Discharge = ",round(qright,3)," CFS ")
```

```
Left Discharge =  1774.862  CFS
Right Discharge =  2408.413  CFS
```

[ ]: