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.

Cleveland
23sep16

1/17

1a)

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

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

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

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

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

$4^{1.852} = 12.553$

$4^{1.1667} =$ ~~10.084~~ 5.6399171

$\pi^{1.852} = 8.3315$

COLLAPSE CONSTANTS

13sep16 2/17

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

ALGEBRA

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

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)

13 sep 16 3/17

1b) $C_h = 145$

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

1c)

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

$= 4.7273 * 3.7261 * 3.9403$

$= 69.4$ 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.

	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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13Sep16

6/17

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

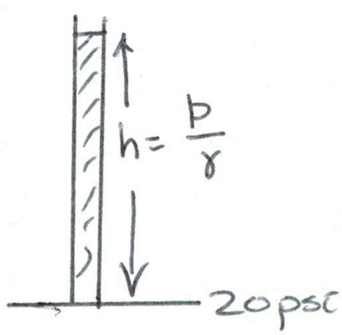
http:\\engineersedge.com/fluid_flow/pipe_roughness.htm (ATTACHED)

$k_s = \frac{0.0002\ inches}{12\ inches} = 0.0000167\ ft$

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

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

2c)



FIND h

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

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

13 Sep 16

7/17

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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13 Sep 16
8/17

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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.

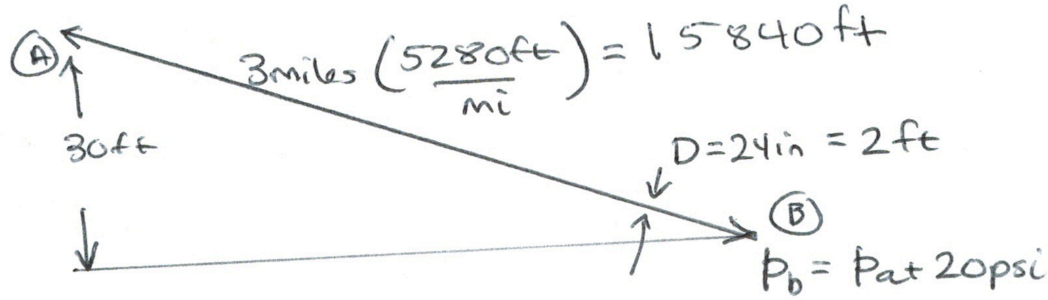
Related Resources:

- 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

13 Sep16

9/17

2d)



ENERGY A → B

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

($z_b = 0$)

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

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

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

$$z_a = 30\,ft$$

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

← PROBABLY FLOWING UPHILL!

IF UPHILL:

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

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

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

∴ WATER FLOWING RIGHT-TO-LEFT

13 Sep 16

10/17

USE SWAMEE JAIN TO ESTIMATE Q

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

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

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

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

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

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

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

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

$$= -4.3982$$

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

13 Sep 16 4/17

— ONLINE CALCULATOR (ATTACHED)

$Q = 9.77\ ft^3/s$

— SPREADSHEET CALCULATOR (ATTACHED)

$Q = 9.77\ ft^3/s$

12/17

Discharge in Pressure Conduit Given Head Loss

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

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

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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13 Sep 16

13/17

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13 Sep 16

14/17

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 ∴ $h_f = 20\ ft$

LENGTH = 5280*2 = 10560 ft

$k_s/D = ?$

$Q = 10\ ft^3/s$

APPLY SWAMEE JAIN FOR D.

$$D = 0.66\left[k_s^{1.25} \cdot \left(\frac{LQ^2}{gh_f}\right)^{4.75} + 21\,Q^{9.4} \cdot \left(\frac{L}{gh_f}\right)^{5.2}\right]^{0.04}$$

NOW EVALUATE PARTS:

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

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

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

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

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

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

$$= 1.787 \text{ ft}$$

CHECK USING ON-LINE TOOL AT

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

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

17/17

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]