

**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

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

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° 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<sup>2</sup>/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](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<sup>2</sup>/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.

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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.

1a)

Cleveland  
93 Sep 16

1/17

$$Q = 1.318 C_n AR^{0.63} S^{0.54}$$

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

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

ALGEBRA

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

MORE ALGEBRA

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

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

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

Now DEAL (EVALUATE) WITH EXPONENTS

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

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

ALGEBRA

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

$$4^{1.852} = 12.553$$

$$4^{1.1667} = 10.08450399171$$

$$\pi^{1.852} = 8.3315$$

COLLAPSE CONSTANTS

13 Sep 16 2/17

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

ALGEBRA

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

Now COLLAPSE AGAIN

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

↑  
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)

$$1b) C_h = 145$$

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

1c)

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

$$= 4.7273 \quad * 3.7261 \quad * 3.9403$$

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

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

Cleared  
13 Sep 16 4/7

Table 6.1 Hazen - Williams coefficients

Pipe Material	Recommended C Value New Pipes®	Design Purpose
<b>Unlined Metallic Pipes</b>		
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
<b>Centrifugally Lined Metallic</b>		
Cast Iron, Ductile Iron and Mild Steel Pipes lined with cement mortar or Epoxy		
Upto 12000 mm dia	140	140
Above 1200	145	145
<b>Projection Methose Cement Mortar Lined Metallic Pipes</b>		
Car Cast Iron, Ductile Iron and Mild Steel Pipes	130*	110**
<b>Non Metallic Pipes</b>		
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 conducted 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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13 Sep 16

A	B	C	D	E	F	G	H
<b>1 Hazen-Williams Head Loss Calculator</b>							
2	INPUTS						
3 Unit System	US	 := Pull Down Menu					
4 Loss Coefficient	145	Table Lookup =>					
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						

## 2a) USE ON-LINE TOOL

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

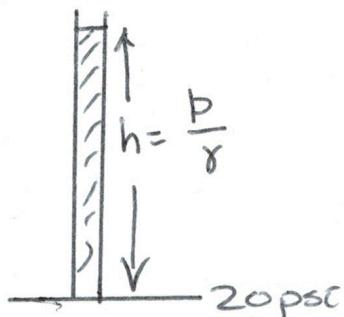
$$V = 1.41 \cdot 10^{-5} \text{ ft}^2/\text{s}$$

2b)  $k_s = 0.0002 \text{ inches}$

[http://engineersedge.com/fluid\\_flow/pipes\\_roughness.htm](http://engineersedge.com/fluid_flow/pipes_roughness.htm) (ATTACHED)

$$\begin{aligned} k_s &= \frac{0.0002 \text{ inches}}{12 \text{ inches}} = 0.0000167 \text{ ft} \\ &= 0.0167 \cdot 10^{-3} \text{ ft} \\ &= 16.7 \cdot 10^{-6} \text{ ft} \quad (16.7 \text{ millifeet}) \end{aligned}$$

2c)

FIND  $h$ 

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

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

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13 Sep 16

9/13/16, 4:58 PM

7/17

# On-Line Water Property Database (US Customary)

Select Water Temperature (Degrees F)

50 degrees F

Water Properties (US Customary) using Python

9/13/16, 4:57 PM

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<sup>3</sup>)

Specific Weight = 62.4 (lbf/ft<sup>3</sup>)

Dynamic Viscosity = 2.73e-05 (lbf-s/ft<sup>2</sup>)

Kinematic Viscosity = 1.41e-05 (ft<sup>2</sup>/s)

Vapor Pressure = 0.178 (lbf/in<sup>2</sup>) - absolute

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9/13/16, 4:59 PM

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.

<b>Pipe Material Roughness Coefficients</b>			
Pipe Material	Specific Roughness Factor, $\epsilon$ , 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](#)

D X

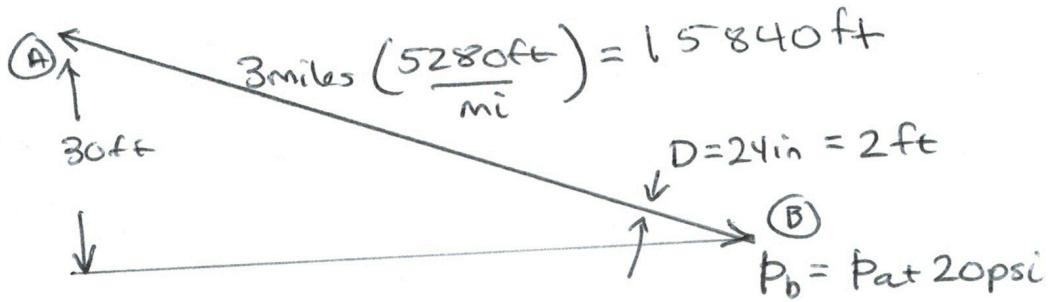
## Trump Betrayed?

Sept. 30 Will Go Down As the Day That  
 Ruins His Presidency. See Why.



GD&T True Position Coordinate  
 Conversion Chart LAMINATED

2d)



ENERGY A → B

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

$$\frac{P_a}{\gamma} - \frac{P_b}{\gamma} + z_a = h_L$$

~~$$\frac{P_a - P_a - 20\text{psi}}{\gamma} + z_a = h_L$$~~

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

$$z_a = 30\text{ ft}$$

$$30\text{ft} - 46.154\text{ft} = -16.154\text{ft}$$

Probably flowing uphill!

IF UPHILL:

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

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

$$\frac{P_a + 20\text{psi}}{\gamma} - \frac{P_a}{\gamma} - 30\text{ft} = h_L = 16.154 \therefore \text{WATER}$$

Flowing RIGHT-TO-LEFT

USE SWAMEE JAIN TO ESTIMATE Q

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

$$\sqrt{\frac{g h_f}{L}} = \sqrt{\frac{32.24(16.154)}{15840 \text{ ft}}} = 0.1812134$$

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

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

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

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

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

$$D^{5/2} \sqrt{\frac{g h_f}{L}} \log_{10} \left( \frac{k_s}{3.7D} + \frac{1.78v}{D^{3/2} \sqrt{\frac{g h_f}{L}}} \right) = (5.6568543)(0.1812134)(-4.2905) \\ = -4.3982$$

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

- ONLINE CALCULATOR (ATTACHED)

$$Q = 9.77 \text{ ft}^3/\text{s}$$

- SPREADSHEET CALCULATOR (ATTACHED)

$$Q = 9.77 \text{ ft}^3/\text{s}$$

# Discharge in Pressure Conduit Given Head Loss

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

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

D = Pipe diameter (in feet or meters)

g = Gravitational acceleration constant (32.2 ft/s<sup>2</sup> or 9.8 m/s<sup>2</sup>)

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<sup>2</sup>/second or meter<sup>2</sup>/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) :

Enter Value for Gravitational acceleration (g in feet/s<sup>2</sup> or meters/s<sup>2</sup>) :

Enter Value for Head loss (hl in feet or meters) :

Enter Value for Pipe Length (L in feet or meters) :

Enter Value for Roughness height (ks in feet or meters) :

Enter Value for Kinematic viscosity (v in feet<sup>2</sup>/second or meter<sup>2</sup>/second) :

=

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]<sup>2</sup>

Head Loss = 16.154 [L]

Pipe Length = 15840.0 [L]

Roughness = 1.67e-05 [L]

Kinematic Viscosity = 1.41e-05 [L]<sup>2</sup>/[T]

----- COMPUTED DISCHARGE -----

Roughness Ratio = 8.35e-06

Discharge = 9.77068045167 [L]<sup>3</sup>/[T]

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

Same As class!  
 Except changed g to us  
 AND changed units labels

3a) VISCOSITY AT 60°F

(USE SAME SOURCE)

<http://cleveland1.ddns.net/cgi-bin/WaterPropertiesUS/WaterProperties.html>

WaterProperties.html

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

b) [https://www.engineersedge.com/fluid\\_flow/Pipe-Roughness.htm](https://www.engineersedge.com/fluid_flow/Pipe-Roughness.htm)

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

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

$$\text{LENGTH} = 5280 * 2 = 10560 \text{ ft}$$

$$k_s/D = ?$$

$$Q = 10 \text{ ft}^3/\text{s}$$

APPLY SWARME JAIN FOR D.

$$D = 0.66 \left[ k_s^{1/25} \cdot \left( \frac{L Q^2}{g h_f} \right)^{4.75} + 2 Q^{9.4} \cdot \left( \frac{L}{g h_f} \right)^{5.2} \right]^{0.04}$$

Now EVALUATE PARTS:

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

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

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

$$zQ^{9.4} = (1.22 \cdot 10^{-5} + \frac{2}{s})(10)^{9.4} = 3.0645 \cdot 10^4$$

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

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

$$= 1.787 \text{ ft}$$

CHECK USING ON-LINE TOOL AT

[http://cleverctrl1.ddns.net/mytoolbox-server/  
Diameter/GivenDischarge/PGivenQ.html](http://cleverctrl1.ddns.net/mytoolbox-server/Diameter/GivenDischarge/PGivenQ.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

# Diameter Given Discharge in a Pressure Pipe

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

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

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) :

Enter Value for Gravitational acceleration (g in feet/s^2 or meters/s^2) :

Enter Value for Head loss (hl in feet or meters) :

Enter Value for Pipe Length (L in feet or meters) :

Enter Value for Roughness height (ks in feet or meters):

Enter Value for Kinematic viscosity (v in feet^2/second or meter^2/second):

= 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]