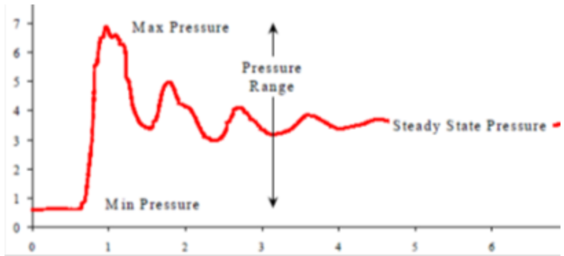


DESIGN AND SELECTION OF PLASTIC PRESSURE PIPE

TECHNICAL BULLETIN

1. INTRODUCTION

Potable water pressure pipes are made from many different materials. The most commonly used pipe materials for municipal water systems are polyvinyl chloride (PVC), ductile iron (DI), high density polyethylene (HDPE), steel (ST) and concrete pressure pipe (CPP). Selecting the right pipe material and the right class of that material, requires an understanding of the system operating conditions and the strengths and weaknesses of each material.

Replacement of current infrastructure piping is estimated to cost billions of dollars. The average age of pipes currently being replaced is about 50 years. Plastic pipes offer high reliability and excellent performance during their service life which is estimated to be at least 100 years if the correct class of pipe is used. It is responsibility of designers to consider the life expectancy of plastic pipe when selecting the pipe material for projects funded from public sources.

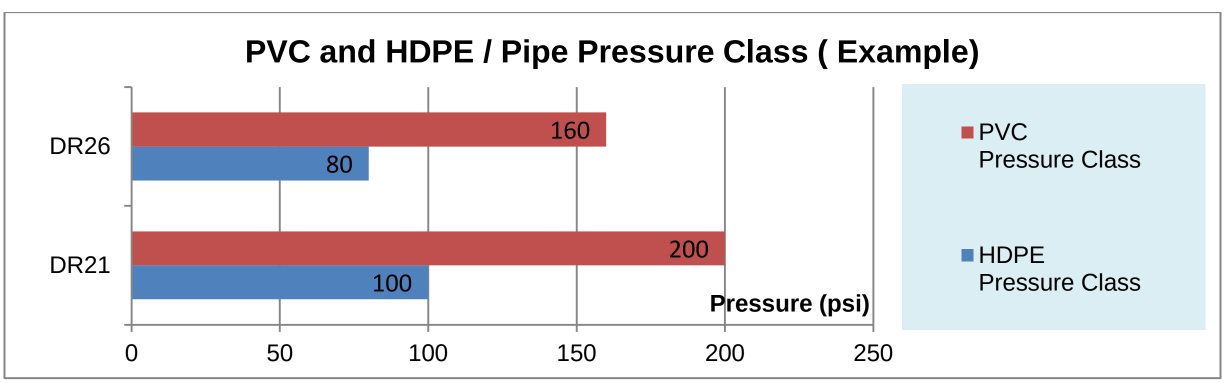
2. PIPE PRESSURE CLASS

The steady state Pressure Class (PC) of a thermoplastic pipe is a function of the allowable hoop stress and the pipe wall thickness. It is calculated in accordance with the ISO equation:

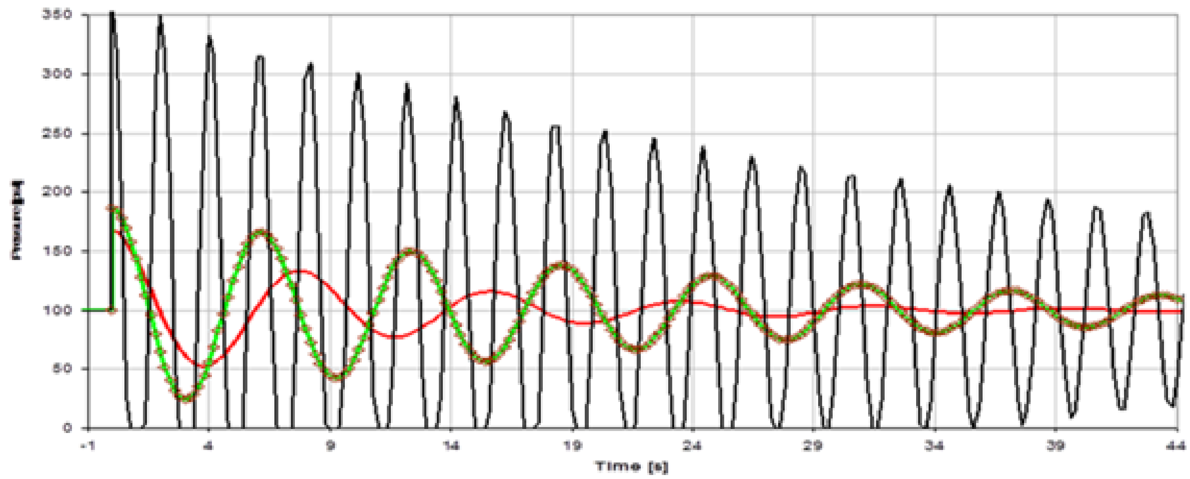
$$PC = \frac{2\ x\ HDS}{DR - 1}$$

HDS = Hydrostatic design stress for water at 73°F, psi

DR = Dimension Ratio = $\frac{Pipe\ Outside\ Diameter}{Minimum\ Wall\ Thickness} = \frac{OD}{t_{min}}$



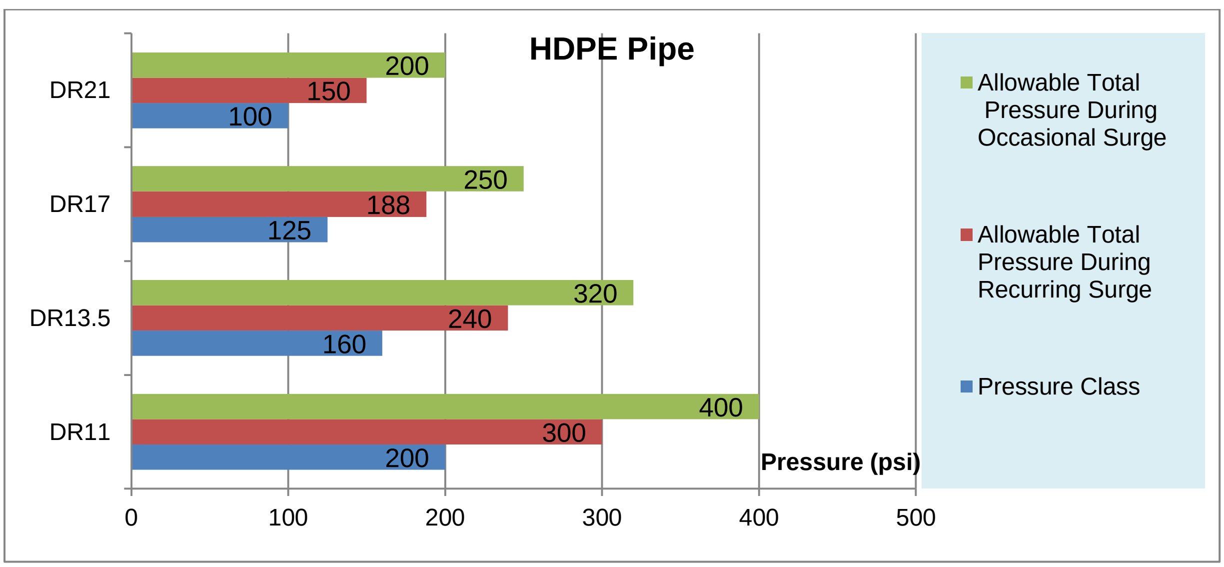
The designer cannot select which pipe (material) to use simply by specifying a pressure class (PC) for the application. There are pressure fluctuations in the system resulting from events such as pump start-up or shut-down and valves opening and closing.



The pressure profile in a pipe due to dynamic system changes in flow velocity is so material property dependent, that there is no obvious simple way for pipes of different materials to have ‘the same’ pressure class. The difference in the ability of pipes of different materials to handle pressures caused by dynamic events means that PC alone cannot be the basis for the pipe selection.

HDPE Pipe:

The pressure class of a polyethylene pipe includes an allowance for surge pressures. The allowance for recurring surge pressures (regular valve and pump operation) is 50% of the pressure class. For occasional surge pressures (unanticipated system failures), the allowance is 100% the pressure class.



PVC Pipe:

PVC pipe excludes any allowances for recurring surge pressure. The allowance for occasional surge pressures is 60% of the pipe’s pressure class (PC). The user is required to calculate the magnitude of the peak surge anticipated and to ensure that the pressure class of the pipe exceeds the working pressure plus the surge pressure.

3. PRESSURE SURGE

Surge pressures (also known as water hammer, hydraulic transients) in liquid transmission systems are caused by sudden changes in the velocity of the fluid flowing in the pipe, which can be produced by valves operating, pump start/stops, power failures, and other operations.

Pressure surges are generally classified as Occasional and Recurring.

- Occasional surge pressure is the result of an infrequent event and is usually the result of a malfunction, such as a power failure or system component failure (such as, pump seize-up, valve-stem failure and pressure relief valve failure).

- Recurring surge pressures occur frequently and are inherent in the design and operation of the piping system (such as, normal pump start-up or shut-down and normal valve opening and closing).

The analysis to determine the magnitude of a pressure surge is based on a full flow stoppage at the maximum flow velocity (Joukowsky equation) and provides a good basis for evaluating surge events considering the range of service conditions that may occur during the life of the pipe. Both ***AWWA M55 PE Pipe—Design and Installation*** *and* ***AWWA M23 PVC Pipe—Design and Installation*** employ this type of analysis method.

The magnitude of the pressure surge caused by sudden changes in the velocity of the flow in a pipe is a function of the change in velocity, the stiffness (modulus) of the pipe, and the resistance to compression (bulk modulus) of the flowing fluid.

$$Ps = a\left(\frac{\Delta v}{2.31g}\right)$$

Ps=surge (psi)

Δv=change in velocity (ft/s)

g=acceleration due to gravity (32 ft/sec²)

a=wave velocity (ft/s)

$$a = \frac{4660}{\sqrt{1 + \frac{Kbulk(DR-2)}{Ed}}}$$

Kbulk = fluid bulk modulus, (300,000 psi for water at 73°F)

Ed = Dynamic instantaneous effective modulus of pipe material, (150,000 psi for HDPE, 400,000 psi for PVC)

DR=dimension ratio

Since the fluid being conveyed is usually water, the only variables are the modulus of the pipe and the design flow velocity.

The design flow velocity used to determine surge pressures can usually be found in Municipal design standards for water distribution systems.

A survey of fifty-seven municipalities in North America (mostly US) for ***Jana's Technical Report on Fatigue of Plastic Water Pipe*** indicates that the average flow velocity for normal flow is 6.7 ft/s (2 m/s) and for fire flow is 11.6 ft/s (3.5 m/s). The ***AWWA Water Distribution Operator Training Handbook*** suggests 5 ft/s (1.5 m/s) as a typical limit for normal operations with higher velocities expected during fire flow conditions.

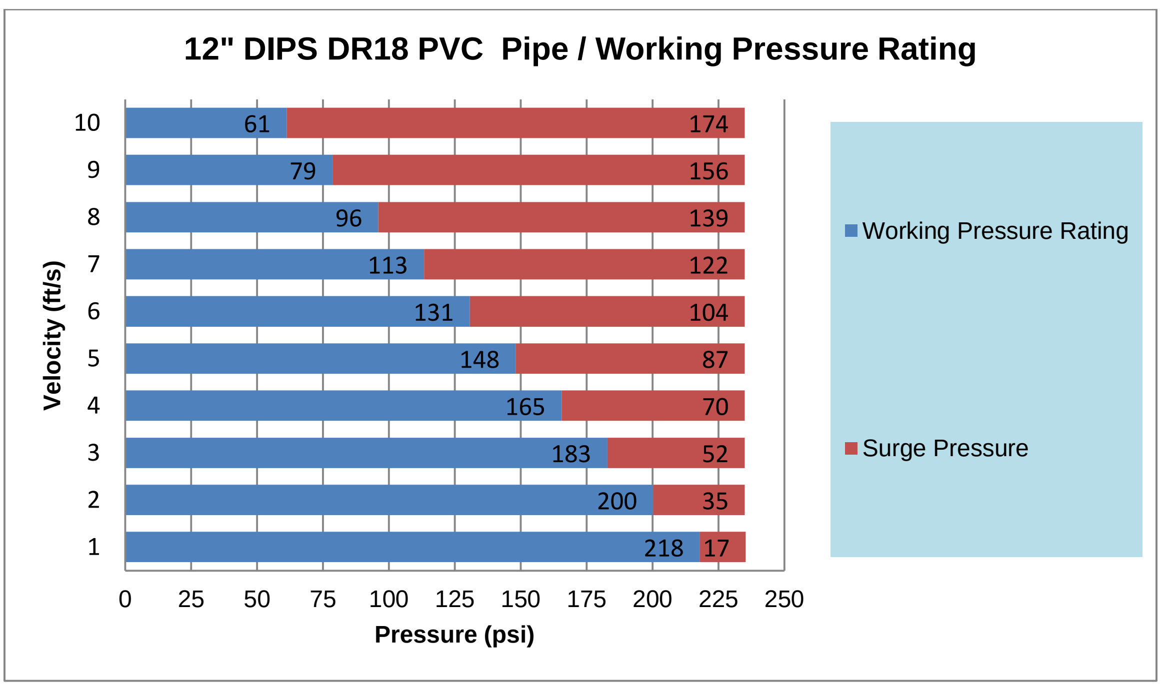
A sampling of design flow guidance of Canadians municipalities suggest that the maximum velocity for normal flow in the pipe shall not exceed 5 ft/s (1.5 m/s) and for fire flow about 8 ft/s (2.4 m/s) to 16.2 fps (5 m/s).

Example: Working Pressure and Surge Assessment of 12" DIPS DR18 PVC pipe and 12" DIPS DR17 PE4710 HDPE pipe.

Dimensional Information:

	12" DIPS DR17 HDPE	**12" DIPS DR18 PVC**
Pipe OD (in)	13.20	13.20
Pipe ID (in)	11.55	11.65
Bore Area (sq.in)	0.73	0.74

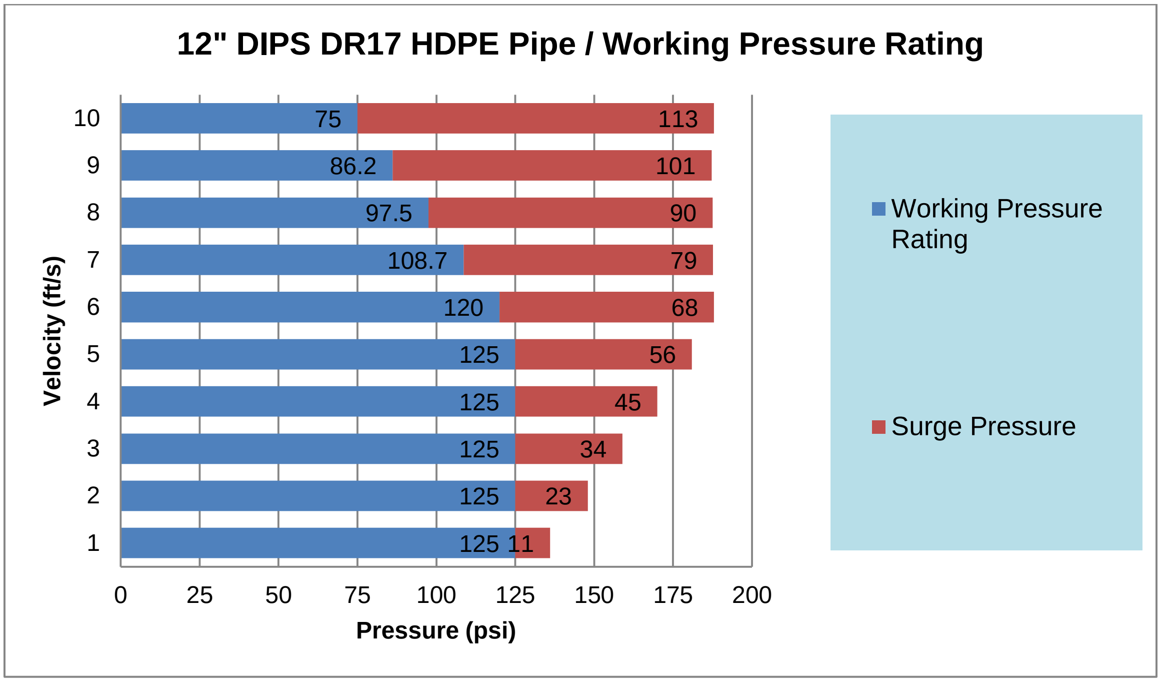
The manufacturer's published pressure class for a PVC DR18 pipe is 235 psi. This rating does not include allowance for recurring surge pressures that might occur. The designer is first required to determine the magnitude of the maximum surge pressure. The working pressure plus the surge pressure shall not exceed the pressure class of the pipe.



Stopping a flow that had a velocity of 5 fps will cause a pressure surge of 87 psi in an 12” DR18 PVC pipe. The working pressure of the PVC pipe should be limited to 148 psi (235 psi -87 psi =148 psi).

Stopping a flow that had a velocity of 8 fps will cause a pressure surge of 139 psi in an 12” DR18 PVC pipe. The working pressure of the PVC pipe should be limited to 96 psi (235 psi -139 psi =96 psi).

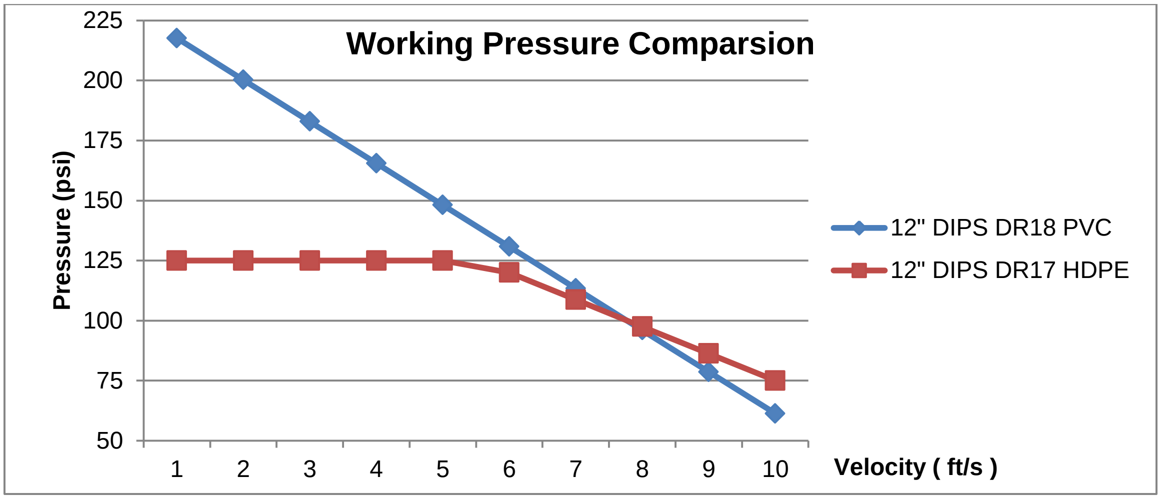
The manufacturer’s published pressure class for a PE4710 DR 17 pipe is 125 psi. The allowable total pressure during surge is 187.5 psi (1.5 X PC =1.5 X 125 psi). The allowable surge allowance is 62.5 psi (187.5 psi – 125 psi).



Stopping a flow that had a velocity of 5 fps will cause a pressure surge of 56 psi in a 12” DR 17 HDPE pipe. The anticipated pressure surge of 56 psi is less than the allowable surge allowance of 62.5 psi. The allowable working pressure of 125 psi need not be reduced since the surge pressure is less than allowable.

Stopping a flow that had a velocity of 8 fps will cause a pressure surge of 90 psi in an 12” DR17 HDPE pipe. The anticipated pressure surge is larger than the surge allowance of 62.5 psi. The working pressure of the HDPE pipe should be limited to 97.5 psi (187.5 psi - 90 psi =97.5 psi).

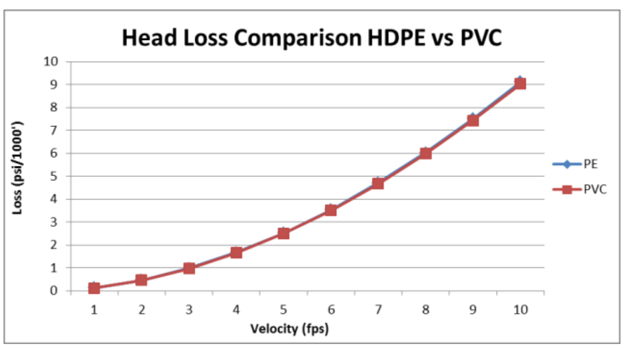
The following graph illustrates the working pressure of PVC and HDPE pipes as a function of flow velocity in the example given above.

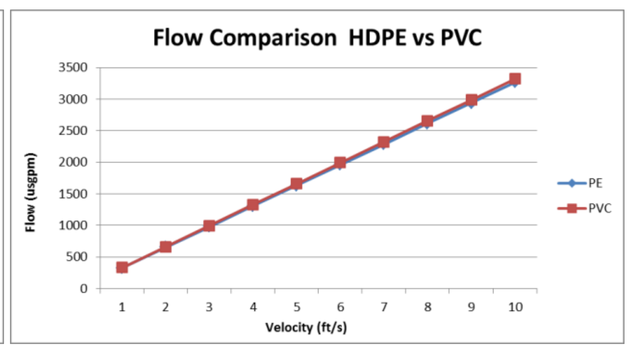


Below design velocity of 5.5 ft/s the working pressure is equal to the pressure class of HDPE (125 psi). Above the design velocity of 5.5 ft/s the working pressure is less than the pressure class of HDPE.

The reduction in working pressure of a PVC pipe below its' pressure class increases as the flow velocity increases. At 7.5 fps the working pressure of the PVC pipe is less than that of the PE pipe.

A graphical depiction of the flow rate (usgpm) and the hydraulic loss for 12" DIPS DR18 PVC and 12" DIPS DR17 HDPE pipe is also presented to provide the reader a quick reference. The results are similar. In fact the plot of PE values is hidden by the plot of PVC results. This is not surprising since the roughness coefficient 'C' for both PVC and HDPE is 150 and both pipe has comparable ID and DR.





4. FATIGUE DESIGN

The number of surge cycles to fatigue failure (NCF) that a plastic pipe can tolerate, is its' fatigue limit. To convert the NCF to a fatigue life of the pipe, the system designer / operator needs to provide an estimate of the frequency of the surge events.

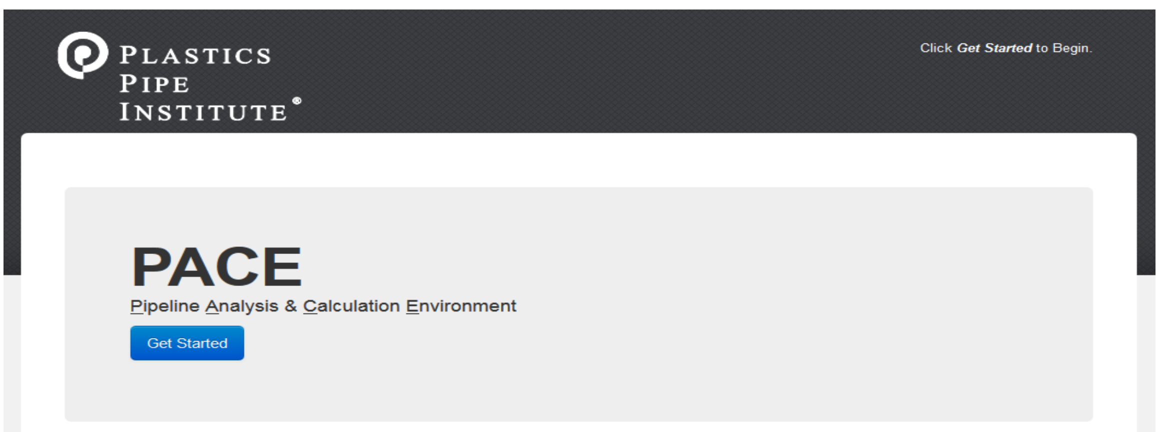
Detailed literature searches conducted for ***Jana's Technical Report on Fatigue of Plastic Water Pipe*** indicates that the current generation of polyethylene materials (PE4710, PE100) are not affected by cycling loading. It is a failure mode that does not appear to occur in service. However, fatigue life calculations are possible and periodic assessment of polyethylene fatigue will confirm the exceptional fatigue resistance of this material.

PVC materials are known to be susceptible to fatigue failure. The PVC pipe industry recommends that users check the suitability of the DR (based on working pressure … pressure rating minus surge pressure) to ensure that fatigue failure is not an issue with the candidate DR.

For additional information on fatigue life and flow velocities see the ***Jana's Technical Report on Fatigue of Plastic Water Pipe*** https://www.plasticpipe.org/pdf/mid-fatigue-plastic-water-pipe-01-12-12.pdf

5. PPI PACE

The Plastic Pipe Institute provides a web based design tool to assist designers and owners in the evaluation of pipe materials for water distribution and transmission main systems. PPI-PACE http://ppipace.com/ allows preliminary calculations of operating pressure, surge pressure and fatigue design life.



The tool follows the design procedures in well-established and accepted water standards (ANSI/AWWA C150/151, ANSI/AWWA C900, ANSI/AWWA C901, ANSI/AWWA C905, ANSI/AWWA C906, ANSI/ASTM D2241).

Design example:

Pipe: 12" DIPS DR17 HDPE PE4710, 12" DIPS (CIOD) DR18 PVC and 12" DIPS PC350 DI

Operating pressure: 70 psi

Design velocity for recurring surge: 5 ft/s

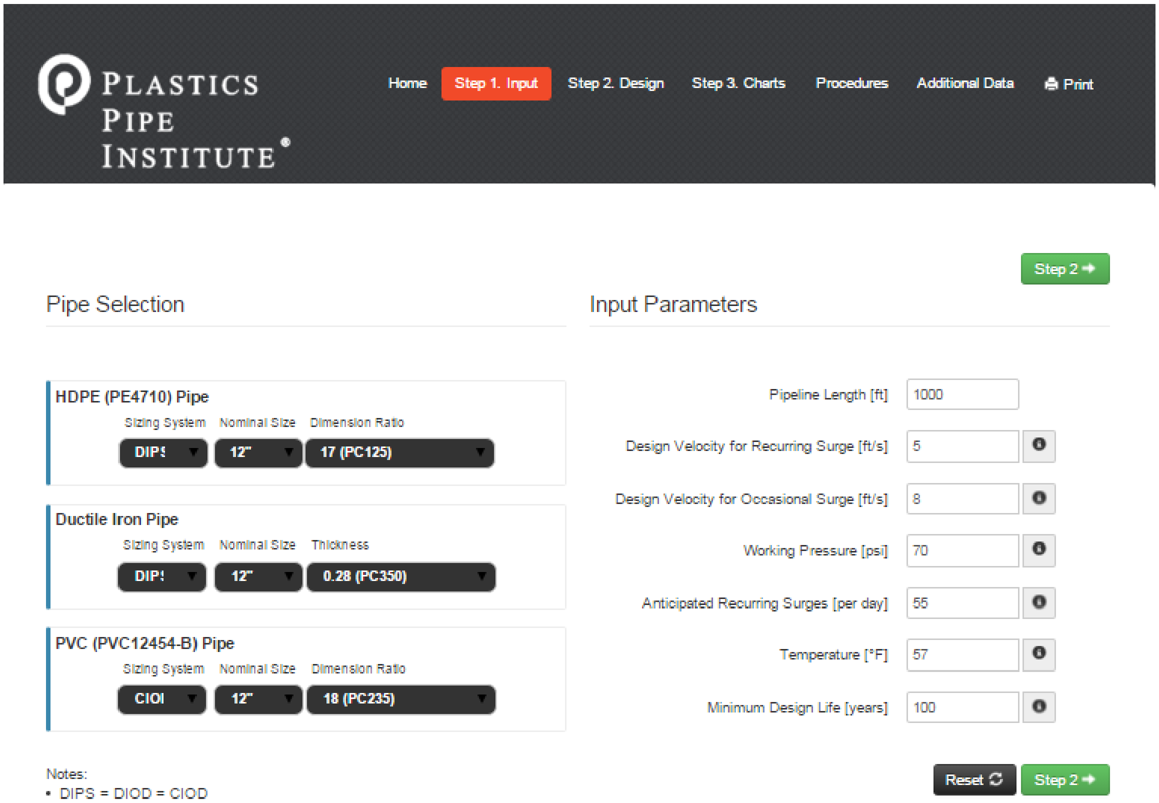
Design velocity for occasional surge: 8 ft/s

Temperature: 57°F

Design life: 100-year

Anticipated recurring surges: 55 cycles/day or about 2 million cycles for a 100-year design life

Step 1: Input



For Recurring Surge, PPI-PACE defaults to 4 fps for design velocity; the software permits entry in the 4-8 fps range.

For Occasional Surge, PPI-PACE defaults to 8 fps for design velocity; the software permits entry in the 5-15 fps range.

For Working Pressure, PPI-PACE defaults to 70 psi - which is the average working pressure in the US. The minimum allowable value in PPI-PACE is 40 psi.

For Anticipated Recurring Surges, PPI-PACE defaults to 55 cycles per day per AWWA C900-07 and AWWA C905-10 (Appendix B/Design Example); this results in about 1 million cycles for a 50-year design life and about 2 million cycles for a 100-year design life. The user should enter the appropriate number.

For Temperature, PPI-PACE defaults to 57°F which is the average water temperature in the US; the software permits entry in the range 40-100°F.

Step 2: Design

Home | Step 1. Input | Step 2. Design | Step 3. Charts | Procedures | Additional Data | Print

← Step 1 | Step 3 →

Additional Design Parameters - *Click Here*

Pressure Pipe Design

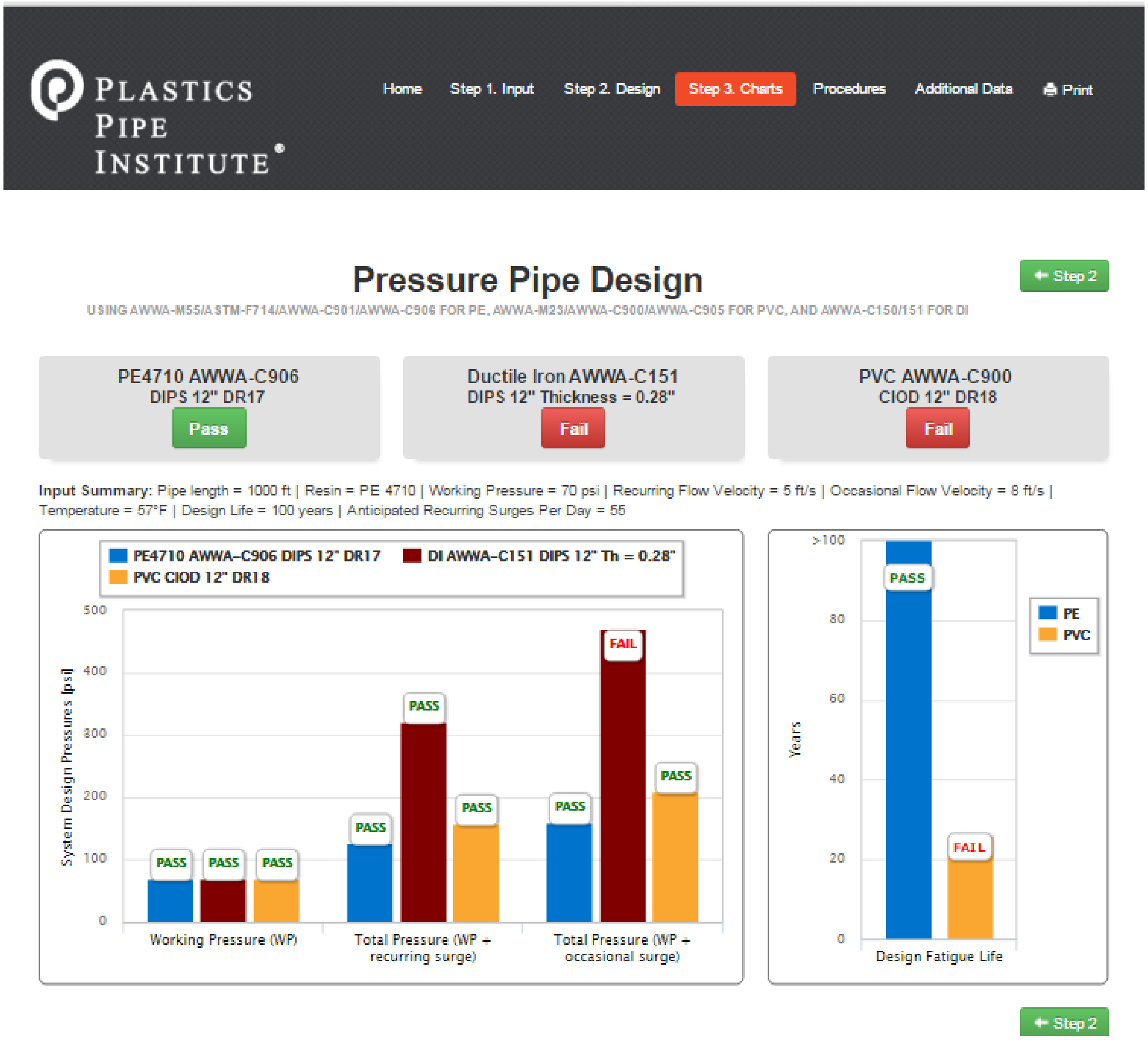
Input Summary: Pipe length = 1000 ft | Resin = PE 4710 | Working Pressure (WP) = 70 psi | Recurring Flow Velocity = 5 ft/s | Occasional Flow Velocity = 8 ft/s | Temperature = 57°F | Design Life = 100 years | Anticipated Recurring Surges Per Day = 55

Result	PASS		FAIL		FAIL	
Material	**PE 4710**		**DI**		**PVC**	
Standard	AWWA-C906		AWWA-C151		AWWA-C900	
Pipe Rating at 57°F (PC x F_T)	125		350		235	
Working Pressure (no surge) Check	O.K.		O.K.		O.K.	
Nominal OD [in]	DIPS 12"		DIPS 12"		CIOD 12"	
Dimension Ratio (DR) or Thickness (TH)	DR = 17		TH = 0.28		DR = 18	
Average Inside Diameter (ID) [in]	11.55		12.52		11.65	
	Recur.	Occas.	Recur.	Occas.	Recur.	Occas.
Flow Rate (Q) [gpm]	1,634	2,614	1,917	3,067	1,660	2,656
Head Loss [psi]	2.5	6.0	2.6	6.2	2.5	6.0
Surge Pressure (P_S) [psi]	56	90	250	401	87	139
Total Pressure (P_T = WP + P_S) [psi]	126	160	320	471	157	209
Allowable Total Pressure During Surge (P_A) [psi]	1.5PC= 188	2.0PC= 250	PC+100= 450	PC+100= 450	1.0PC= 235	1.6PC= 376
Surge Pressure Check ($P_T \le P_A$)	O.K.	O.K.	O.K.	x	O.K.	O.K.
Number of Cycles To Failure	3.7×10^8	-	-	-	1.0×10^6	-
Design Fatigue Life [years; with SF = 2]	≥100	-	-	-	26	-
Design Fatigue Life Check	O.K.	-	-	-	x	-

← Step 1 | Step 3 →

The design fatigue life for PVC is determined using the calculation method stated in AWWA C900 and C905 Appendix B using a 2:1 design factor. For PE the design fatigue life is determined using fatigue curves provided in *Marshall, G.P., Brogden, S: Final report of Pipeline Innovation Contract to UKWIR, 1997* using a 2:1 design factor. The design fatigue life of Ductile Iron (DI) pipe is not shown in PPI-PACE since DI is not considerable to be fatigue limited. The only design check is about pressure capability. The 'right pipe' is the one that meets design requirements for flow, working pressure, and fatigue life.

Step 3: Charts



Printed report:

Calculated Results

Standard	**AWWA-C906**		**AWWA-C151**		**AWWA-C900**	
Resin	PE4710		DI		PVC12454-B	
Pipe Rating at 57°F	125		350		235	
Working Pressure (no surge) Check	OK		OK		OK	
Nominal OD [in]	DIPS 12		DIPS 12		CIOD 12	
Dimension Ratio / Thickness	17		0.28		18	
Average Inside Diameter [in]	11.55		12.52		11.65	
	Recur.	Occas.	Recur.	Occas.	Recur.	Occas.
Flow Rate [gpm]	1,634	2,614	1,917	3,067	1,660	2,656
Head Loss [psi]	2.5	6.0	2.6	6.2	2.5	6.0
Surge Pressure [psi]	56	90	250	401	87	139
Total Pressure [psi]	126	160	320	471	157	209
Allow. Total Press. (with surge) [psi]	188	250	450	450	235	376
Surge Pressure Check	OK	OK	OK	x	OK	OK
Number of Cycles To Failure	3.7×10^8		N/A		1.0×10^6	
Design Fatigue Life [years; SF = 2]	>100		N/A		26	
Design Fatigue Life Check	OK		N/A		x	

6. Conclusions

Different pipe materials define pressure class very differently. Designers should not compare pipe alternatives simply by pressure class. The pressure class specified for PE (and PVC) should be based on the AWWA design methods applicable to each material, as illustrated in this Technical Bulletin.

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