WATER FLOW CHARACTERISTICS OF THERMOPLASTIC PIPE

Foreword

This software was developed and published with the technical help and financial support of the members of the Plastics Pipe Institute (PPI). The members have shown their interest in quality products by assisting independent standard-making and user organizations in the development of standards, and also by developing reports on an industry-wide basis to help engineers, code officials, specifying groups, and users.

The purpose of this software is to provide essential information on the water flow characteristics or properties of thermoplastic pipe. The term pipe as used in this report also includes tubing.

This software has been prepared by the Plastics Pipe Institute as a service to the industry. The information in this software is offered in good faith and believed to be accurate at the time of its preparation, but is offered without any warranty, expressed or implied. Additional information may be needed in some areas, especially with regard to unusual or special applications. Consult the manufacturer or material supplier for more detailed information. A list of member manufacturers is available from PPI. PPI does not endorse the proprietary products or processes of any manufacturer and assume no responsibility for compliance with applicable laws and regulations.

The Plastics Pipe Institute intends to revise this software from time to time, in response to comments and suggestions from users of the software. Please send suggestions or improvements to the following address:

Plastics Pipe Institute
1825 Connecticut Ave., NW
Suite 680
Washington, DC 20009
Phone: 202-462-9607
Fax: 202-462-9779
Web: www.plasticpipe.org

A literature list that includes all Technical Reports, Technical Notes, brochures, films, slide presentations, and other available information, may be obtained from the Plastics Pipe Institute.

This software was first issued in March, 1971, as a written Technical Report , and was revised in June, 1992. In April, 2000 , the written report was adapted to create this software program and accompanying online documentation.

TABLE OF CONTENTS

WATER FLOW CHARACTERISTICS OF THERMOPLASTIC PIPE

1. INTRODUCTION

During the past 30 years, the use of thermoplastic piping in water and sewer systems has increased significantly. There are many reasons for this wide acceptance, but one of the primary characteristics which makes thermoplastic piping attractive to designers is the low resistance to flow that this piping offers.

This report gives information on the range of pipe sizes commonly used in water and sewer systems. The tables contained in the appendices give the flow capacities of standard sizes of thermoplastic pipe in terms of velocity and head loss due to friction in pressure piping systems. Similarly, tables are presented that demonstrate the relationship of slope to flow velocity for thermoplastic pipe used in gravity flow applications.

The information in this report applies to all types of thermoplastic materials used for water and sewer systems. These pipes are made by the same basic extrusion technique, which results in smooth inside surfaces.

2. HEAD LOSS IN PRESSURE PIPES

A number of empirical formulae have been developed to solve problems involving positive pressure flow in pipes. All of these depend, to some extent, on experimentally determined coefficients. The most commonly accepted approximations for pressurized flow applications are the Darcy-Weisbach Formula and the Hazen-Williams Equation.

2.1. Darcy-Weisbach Formula

The Darcy-Weisbach Formula for head loss in a circular pipe is:

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

Where:

HL = Head Loss in feet
f = Darcy-Weisbach friction factor (approximated from Moody Diagram)
L = Length of pipe in feet
D = Inside diameter in feet
V = Average flow velocity in feet per second
g = Gravitational constant = 32.2 feet/second/second

As indicated above, the Darcy-Weisbach friction factor is a function of the Reynolds Number for the piping system under consideration. The Reynolds Number is a dimensionless number relating the fluid velocity, pipe diameter, and fluid viscosity. This relationship is:

$$R_N = V \times \frac{D}{m}$$

Where:

R_N = Reynolds Number
V = Average flow velocity in feet per second
B = Inside diameter of the pipe in feet
m = Kinematic fluid viscosity in feet-feet per second

Having determined the Reynolds Number, the friction factor, f, may then be obtained from the smooth pipe curve of the Moody Diagram (see Appendix VIII). This value, along with the other variables, is then substituted into the Darcy-Weisbach Formula to solve for head loss.

Although the Darcy-Weisbach Formula is generally regarded as the most accurate means of relating head loss and flow, it can prove cumbersome to use due to the iterative nature of its solution. Standard practice in most situations is to then utilize a less accurate but acceptable method of calculation of flow or head loss that closely approximates the flow conditions under consideration.

2.2. Hazen-Williams Formula

One of the most commonly accepted formulas for head loss approximation and the basis for the pressurized flow tables in this report is the Hazen-Williams Equation. This relationship, expressed as a function of pressure loss in feet per 100 feet of pipe, is presented below. It is the expression that serves as the basis for the values presented in the appendices in Tables 1 through 30 for pressurized flow.

$$HL = 0.2083 \times \frac{100^{1.852}}{C^{1.852}} \times \frac{Q^{1.852}}{d^{4.8655}}$$

Where:

HL = Head Loss in feet per 100 feet of pipe
C = Hazen-Williams Flow Factor
= 150 for thermoplastic pipe
Q = Volumetric Flow Rate in gallons per minute
d = Pipe inside diameter in inches

The volumetric flow rate can be converted to flow velocity by using this equation:

$$V = \frac{0.40085 \times Q}{d^2}$$

Where:

V = Flow velocity in feet per second
Q = Volumetric Flow Rate in gallons per minute
d = Pipe inside diameter in inches

Other forms of the Hazen-Williams Formula are contained in Appendix IV. Any of these forms of the Formula can be assumed to be relatively accurate for piping systems in which the Reynolds Number is greater than 10^5 That is, where the flow velocity multiplied by the pipe inside diameter is greater than 15 for water flow.

As noted above, a Hazen-Williams Flow Factor of 150 is recommended for thermoplastic pipes. This value is based upon laboratory tests and field experience. Test results have yielded higher values in the range of 155 to 165, but the use of a value of 150 is conservative in nature and, therefore, aids in providing a further factor of safety to the design.

3. GRAVITY FLOW

3.1. Hazen-Williams Formula

The Hazen-Williams Formula may be used for the approximation of gravity flow as well as pressurized flow. As indicated previously, various forms of this formula are presented in Appendix IV.

3.2. Manning Equation

A more commonly accepted approximation for gravity flow is the Manning Equation. This relatively straightforward equation is:

$$V = \frac{1.486 \times R^{0.667} \times S^{0.5}}{n}$$

Where:

V = Average flow velocity in feet per second
R = Hydraulic radius in feet
= ID/4 for full flow
= Cross sectional area of flow / wetted perimeter
S = Slope in feet per foot
n = Manning flow coefficient

Various forms of this equation are presented in Appendix V.

Tables 31 through 46 have been developed for full flow conditions assuming an “n” factor of 0.010. Practical experience has shown that this value represents a reliable, conservative approximation of the flow properties associated with polyethylene pipe.

4. DESIGN VELOCITY AND TOTAL ALLOWABLE PRESSURE

The maximum allowable water velocity in thermoplastic piping systems is a function of the design of a specific system and its operating conditions.

In general, design velocities of 5 to 10 feet per second are considered normal. Further details on flow velocities and total allowable pressures can be found in Appendix I.

5. CORROSION ALLOWANCE

Contrary to the experience with some other piping products, no allowance for corrosion and, therefore, subsequent lowering of flow capacity, has to be included in the Tables that are used in this report. Field experience in North America and Europe over the past 30 years indicates that the flow characteristics in older thermoplastic lines are essentially unchanged over time.

6. FITTINGS

A piping installation consists of straight pipe, bends, elbows, tees, valves, and various other obstructions to flow. The most common approach is to express the loss through a fitting as being the number of linear feet of pipe that sustains the same loss. In calculating the head loss through a piping system, it is then only necessary to evaluate the total number of feet of straight pipe plus the equivalent length of pipe represented by the fittings under consideration. The equivalent lengths of straight pipe for various fittings, expressed as a function of pipe diameter, is presented in Appendix VI.

7. REFERENCES

American Sewer Design, American Iron and Steel Institute, New York, NY, 1980.

Brockman, Marion R., Journal of Research of the National Bureau of Standards, 58-51(1957), p.2734.

Handbook of PVC Pipe, Uni-Bell PVC Pipe Association, Dallas, TX, Sept., 1991.

Hunter, Roy B., Report of the National Bureau of Standards, BMS 79, “Water Distributing Systems for Buildings,” Nov., 1941.

Partker, J. D., James H. Boggs, and Edward F. Blick, Introduction to
Fluid Mechanics and Heat Transfer, Addison-Wesley Publications, February, 1974.

“Standards for Plastics Piping,” Technical Report PPI-TR-5 of the Plastics Pipe Institute, 1990.

APPENDIX I

LIMITING WATER VELOCITIES IN THERMOPLASTICS PIPING SYSTEMS

The maximum water velocity in a thermoplastic piping system depends on the specific details of the system, the character of the flow stream, and the system operating conditions.

In general, design velocities of 5 to 10 feet per second are being used and are considered normal. Higher flow velocities are common in certain applications including gravity and slurry flow. However, in all instances, careful consideration should be given to the effect that flow velocity will have on overall piping system performance in light of valve, pump, and system operation. Particular attention should be given to possible effects of excessive velocity on pipe abrasion rate and on pressure surges that may be generated by sudden or rapid changes in flow velocity.

Recommendations for pressure surge design, which are given in design standards or offered by piping manufacturers, should be followed.

In the case of a polyethylene piping system, the working pressure of the system plus recurrent surge pressure associated with a specific piping arrangement or operation should not exceed 150% of the pipe pressure rating. Occasional surge pressures in excess of this limit are allowable so long as the total of the expected surge plus the working pressure of the system does not exceed 200% of the pipe pressure rating.[1]

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[1] AWWA Standard for Polyethylene (PE) Pressure Pipe and Fittings, 4 in. through 63 in., for Water Distribution, C-906, American Water Works Association, Denver, CO, 1990.

APPENDIX II

EQUATION TERMINOLOGY

The following terms are used in the equations contained within Appendix III and Appendix IV of this report:

C	Hazen-Williams Flow Coefficient
D	Inside diameter of pipe in feet
d	Inside diameter of pipe in inches
f	Darcy-Weisbach Friction Factor
g	Gravitational acceleration, generally accepted as being 32.2 feet per second per second
HL	Head loss in feet of water
L	Length of pipe in feet
n	Manning Flow Coefficient
Q	Volumetric flow rate in cubic feet per second
q	Volumetric flow rate in gallons per minute
R	Hydraulic radius in feet (the ratio of flow area to wetted perimeter)
R_N	The Reynolds Number (a dimensionless number relating flow, diameter, and fluid viscosity)
S	Slope of hydraulic grade line in feet per foot
V	Average flow velocity in feet per second
m	Kinematic fluid viscosity in feet - feet per second

APPENDIX III

FORMS OF THE HAZEN-WILLIAMS FORMULA

Velocity:

$$V = 1.318CR^{0.63}S^{0.54}$$

$$V = 0.550CD^{0.63}S^{0.54}$$

$$V = 0.115Cd^{0.63}S^{0.54}$$

Flow:

$$Q = 16.66CR^{2.63}S^{0.54}$$

$$Q = 0.432CD^{2.63}S^{0.54}$$

$$Q = 0.000627Cd^{2.63}S^{0.54}$$

$$q = 7427CR^{2.63}S^{0.54}$$

$$q = 193.9CD^{2.63}S^{0.54}$$

$$q = 0.281Cd^{2.63}S^{0.54}$$

Head Loss:

$$HL = 0.600 \times \frac{V^{1.85}}{C^{1.85}R^{1.17}}$$

$$HL = 3.04 \times \frac{V^{1.85}}{C^{1.85}D^{1.17}}$$

$$HL = 54.66 \times \frac{V^{1.85}}{C^{1.85}d^{1.17}}$$

$$HL = 0.00556 \times \frac{Q^{1.85}}{C^{1.85}R^{4.87}}$$

$$HL = 4.72 \times \frac{Q^{1.85}}{C^{1.85}D^{4.87}}$$

$$HL = \frac{841500 \times Q^{1.85}}{C^{1.85}d^{4.87}}$$

$$HL = \frac{6.936 \times 10^{-8} \times q^{1.85}}{C^{1.85}R^{4.87}}$$

$$HL = \frac{5.8616 \times 10^{-5} \times q^{1.85}}{C^{1.85}D^{4.87}}$$

$$HL = \frac{10.47 \times q^{1.85}}{C^{1.85}d^{4.87}}$$

APPENDIX IV

FORMS OF THE MANNING EQUATION

Velocity (pipes flowing full):

$$V = \frac{1.486}{n} \times R^{0.667} \times S^{0.5}$$

$$V = \frac{0.113}{n} \times d^{0.667} \times S^{0.5}$$

$$V = \frac{0.590}{n} \times D^{0.667} \times S^{0.5}$$

Flow (pipes flowing full):

$$Q = \frac{0.463}{n} \times D^{2.667} \times S^{0.5}$$

$$q = \frac{207.8}{n} \times D^{2.667} \times S^{0.5}$$

$$Q = \frac{0.00613}{n} \times d^{2.667} \times S^{0.5}$$

$$q = \frac{0.275}{n} \times d^{2.667} \times S^{0.5}$$

Slope (pipes flowing full):

$$S = \frac{0.453 V^2 n^2}{R^{1.33}}$$

$$S = \frac{2.66 \times 10^6 Q^2 n^2}{d^{5.33}}$$

$$S = \frac{2.873 V^2 n^2}{D^{1.33}}$$

$$S = \frac{2.316 \times 10^{-5} q^2 n^2}{D^{5.33}}$$

$$S = \frac{78.31 V^2 n^2}{d^{1.33}}$$

$$S = \frac{13.22 q^2 n^2}{d^{5.33}}$$

$$S = \frac{4.665 Q^2 n^2}{D^{5.33}}$$

APPENDIX V

APPROXIMATE FRICTION LOSS IN THERMOPLASTIC PIPE FITTINGS

(in feet of pipe)

Type of Fitting	Equivalent Length of Pipe (in feet)
Tee, flow through main	20D[*]
Tee, flow through branch	60D
90° Elbow, molded, R = 1.5 D	30D
90° Elbow, mitered, R = 1.5 D	24D
60° Elbow, mitered, R = 1.5	16D
45° Elbow, molded, R = 1.5 D	16D
45° Elbow, mitered, R = 1.5 D	12D
30° Elbow, mitered, R = 1.5 D	8D
Insert Couplings	12D
Male-Female Insert Adapters	18D

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[*] D is the inside diameter of the pipe in feet.

APPENDIX VI

INSIDE DIAMETER DETERMINATIONS

REFERENCE STANDARDS

ASTM D 2239, “Standard Specification for Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter”

ASTM D 2447, “Standard Specification for Polyethylene (PE) Plastic Pipe, Schedules 40 and 80, Based on Outside Diameter”

ASTM D 2666, “Standard Specification for Polybutylene (PB) Plastic Tubing”

ASTM D 2737, “Standard Specification for Polyethylene (PE) Plastic Tubing”

ASTM D 2846, “Standard Specification for Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Hot- and Cold-Water Distribution System”

ASTM D 3309, “Standard Specification for Polybutylene (PB) Plastic Hot- and Cold-Water Distribution Systems”

ASTM F 876, “Standard Specification for Crosslinked Polyethylene (PEX) Tubing”

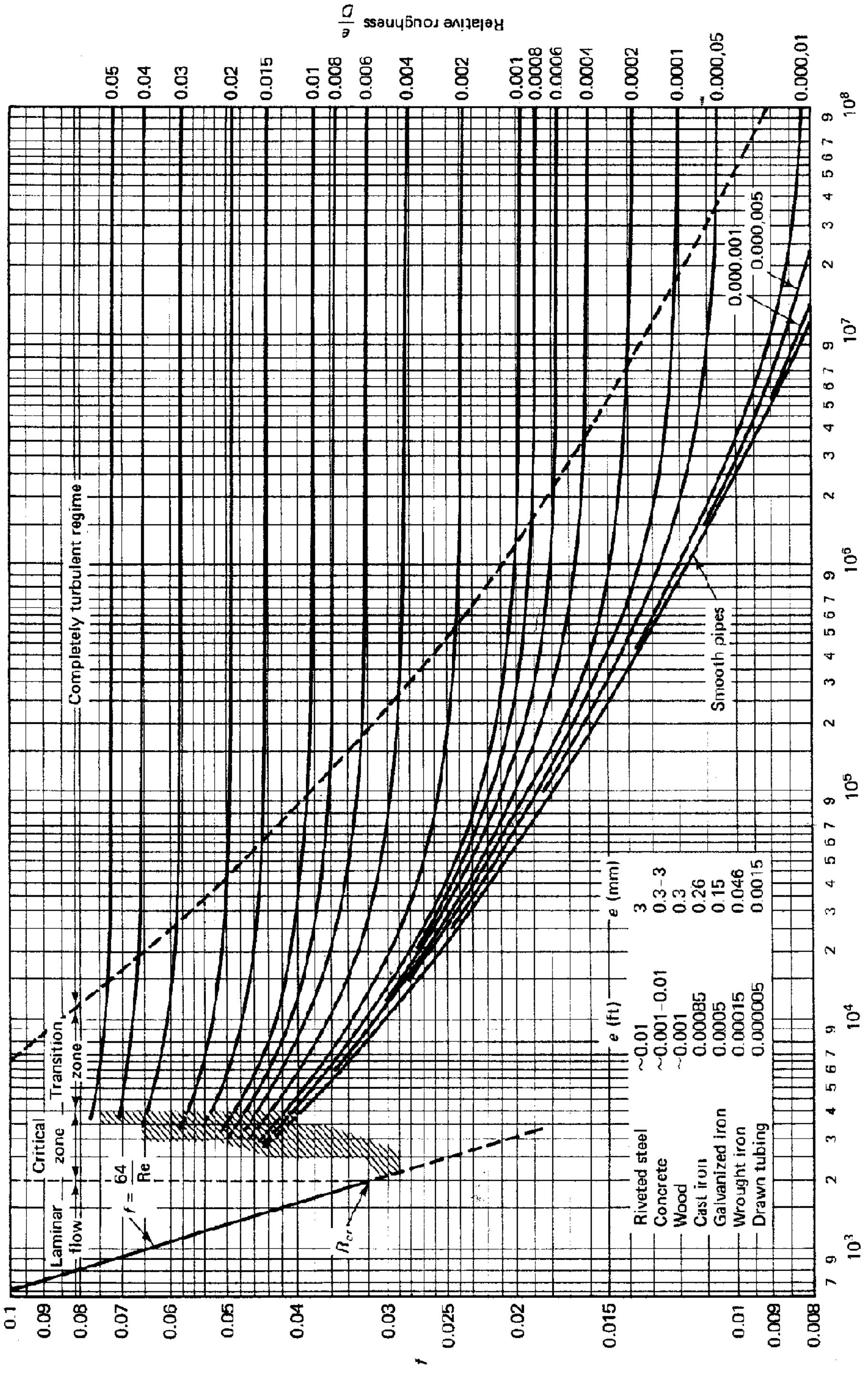
ASTM F 877, “Standard Specification for Crosslinked Polyethylene (PEX) Plastic Hot- and Cold-Water Distribution Systems”

AWWA C 901, “Polyethylene (PE) Pressure Pipe and Tubing, 1/2 In. Through 3 In., for Water Service”

AWWA C 906, “Polyethylene (PE) Pressure Pipe and Fittings, 4 In. Through 63 In., for Water Distribution”

APPENDIX VII

MOODY DIAGRAM



Source: Transactions, ASME, Vol. 66 (1944), L.F. Moody, American Society of Mechanical Engineers, New York, NY