PLASTICS

Learn Their Role in Plumbing System Design

By David Chasis

Plastics are a suitable piping product in many underground applications such as irrigation, swimming pools, drainage, well casings, sewer lines, slip-lining, hot and cold water distribution, and gas distribution. This article explores these applications as well as the many aboveground opportunities for plastic pipe usage in industrial and commercial applications. For purposes of this article, soft flexible tubing, plastic-lined metal piping, and fiber-reinforced piping are excluded.

INTRODUCTION TO PLASTIC

Plastic is a synthetic material made from polymeric substances of large molecular weight. Although plastic is solid in its finished state, it can be shaped by flow at some stage in its manufacture or processing. The word *plastic* is derived from the Greek word *plastikos* or the Latin word *plasticas,* both meaning "to be molded."

The plastic industry celebrated its 100-year anniversary in 2007. The first all-synthetic plastic, phenol formaldehyde (Bakelite), was discovered in 1907. However, it was not until World War II and post-war industrial demands that polyvinyl chloride (PVC) and polyethylene (PE) plastics were used for piping. Acrylonitrile butadiene styrene (ABS) and polypropylene (PP) were introduced in the 1950s. Chlorinated polyvinyl chloride (CPVC), polyvinylidene fluoride (PVDF), and cross-linked polyethylene (PEX) were introduced in the 1960s.

The plastics used in piping today are compounds formulated from basic resins such as PE, PVC, PP, and CPVC with various additives (see Figure 1). The additives are incorporated in the resin or added during the manufacturing process to provide the desired product performance characteristics.

The two most commonly used manufacturing methods to create plastic piping products are extrusion and injection molding. All thermoplastic piping is extruded. Extrusion is a process whereby heated plastic forced through a shaping orifice becomes one continuous formed piece. Most voluminous thermoplastic non-pipe products are injection molded. Injection molding is the process of forming a material by forcing it, under pressure, from a heated cylinder through a sprue (runner) into the cavity of a closed mold (see Figure 2).

Figure 1 Plastic resin and compounds

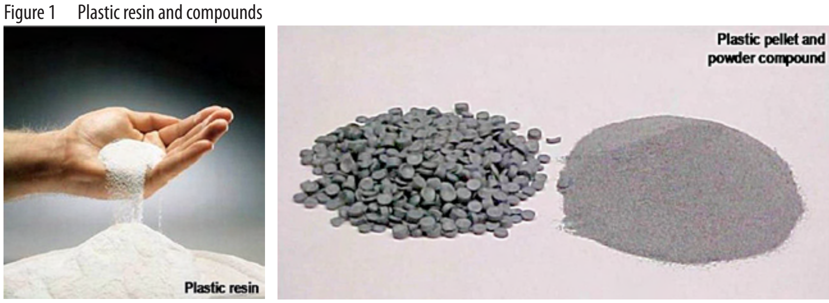
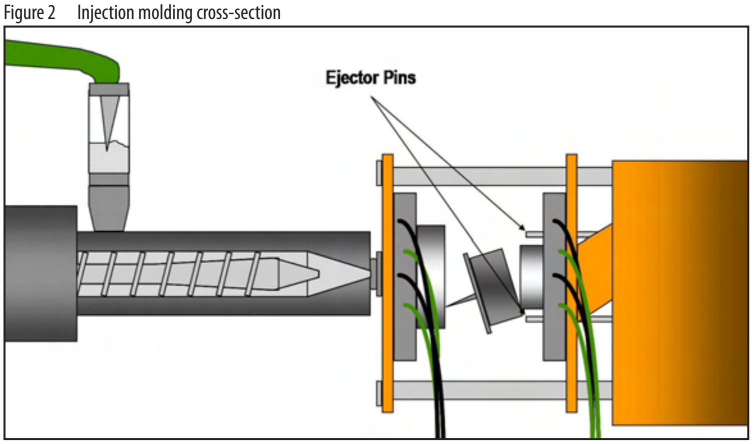


Figure 2 Injection molding cross-section



Almost all plastic piping used in North America is made from materials having common physical characteristics as classified by ASTM International standards. Despite a movement to redefine the classifications in a more meaningful way, the old designations are still in use. For example, in the past (and also being used presently in piping markings), PVC pipe material commonly had the designation 1120. The first digit depicts the type of PVC, the second digit is the grade of PVC, and the last two digits equal the hydrostatic design stress of the material divided by 100. The new ASTM designation for PVC is done by cell classification, which considers the material and its impact strength, tensile strength, modulus of elasticity, and heat deflection temperature. A typical PVC cell classification is 12454.

To ensure compatibility of plastic piping materials, ASTM has created test methods for determining such physical characteristics as specific gravity, tensile strength, modulus of elasticity, flexural strength, impact strength, coefficient of thermal expansion, thermal conductivity, and others.

FEATURES AND BENEFITS

All plastics offer the following features of thermoplastic materials.

Chemical Resistance

This applies to both the interior of plastic piping, which is unaffected by abrasive or otherwise contaminated materials flowing through the piping, and the exterior of the piping, where installation in aggressive soil and water conditions may damage other piping materials. Plastic piping does not require a protective coating in these situations. In fact, plastic piping often is recommended because its chemical resistance leads to longevity.

Figure 3 Uncorroded plastic pipe

Corrosion Resistance

Plastic piping is nonconductive and therefore immune to galvanic or electrolytic corrosion attack (see Figure 3). No expensive prevention equipment or coatings are required.

Optimum Flow

Because of their smooth interior surfaces, all plastic pipes have a Hazen-Williams C factor of 150. Less turbulent flow lowers velocities and lessens horsepower requirements.

Lightweight

Most plastic piping is one-sixth the weight of other piping materials. The light weight dramatically lowers transportation cost, simplifies storage and on-site handling, and allows safer and easier piping installations (see Figure 4).

Abrasion Resistance

Many plastics are much more resistant to abrasion than non-plastic pipe, which means less wear on the pipe, especially when slurries are involved.

Figure 4 Man carrying fitting

Low Thermal Conductivity

All plastic piping materials have low thermal conductance, resulting in less heat loss through the wall of the pipe. In many cases, insulation may be eliminated or greatly reduced from the installation.

Variety of Joining Methods

Every plastic piping system has three or more joining options. Two of the joining methods, heat fusion and solvent cement, create joints stronger than the pipe or fitting being joined.

Variety of Colors

The manufacturing process for plastic piping allows color to be an integral part of the piping system. Color-coding pipes allows a visual safety factor in underground piping applications (see Figure 5).

Figure 5 Various colored plastic piping

Nontoxic, Odorless, and Biological Resistance

Plastic piping systems are odorless, nontoxic, and resistant to fungi, bacteria, and termite attacks. These characteristics allow plastics to be used in the food and beverage industry as well as high-purity piping systems. In high-purity and ultra-high-purity water systems, specially formulated non-pigmented PVDF and PP piping materials frequently are used to obtain maximum water purity results.

Code Acceptance

Dozens of plastic piping standards are referenced in plumbing and mechanical codes, including the International Plumbing Code and Uniform Plumbing Code. Some of these standards include:

- ASTM D1785-06: *Standard Specification for Polyvinyl Chloride (PVC) Plastic Pipe, Schedules 40, 80, and 120*
- NSF/ANSI Standard 14: *Plastic Piping System Components and Related Materials*
- UL 94: *Standard for Flammability of Plastic Materials for Parts in Devices and Appliances*
- FM 4910: *Fire-safe Plastics for Semiconductor Equipment*

Integrated Piping Systems

Most plastics come in complete systems of fluid-handling and air-handling products, allowing one plastic material to be in contact with all wetted parts.

Ease of Fabrication

Thermoplastic piping materials can be easily fabricated into many diverse products due to ease of construction.

Ease of Product Identification

Like copper and cast iron pipe, most plastic piping products have surface markings showing country of origin, material, pipe size, pressure rating, manufacturer, applicable certification or listing agency, and manufacturing process cycle (see Figure 6).

Figure 6 Product markings

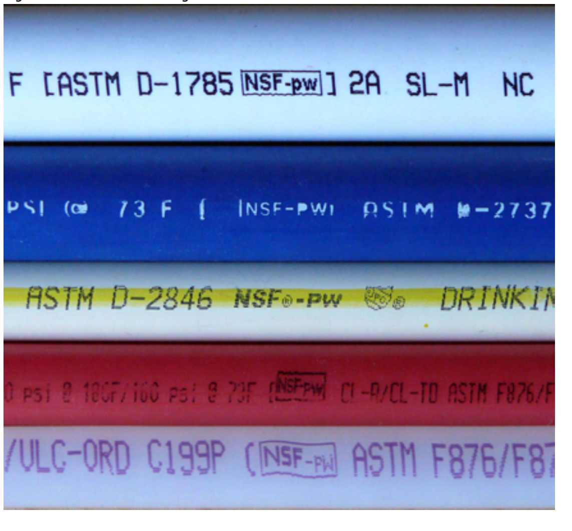


Figure 7 Typical chemical-resistance table

Chemical - Inorganics	CPVC	PE	PP	PVC	PVDF
Acids, dilute	R	R	R	R	R
Acids, concentrated	R	L	L	R	R
Acids, oxidizing	R	NR	NR	R	R
Alkalis	R	R	R	R	R
Acid gases	R	R	R	R	R
Ammonia gases	NR	R	R	L	R
Halogen gases	L	L	L	L	R
Salts	R	R	R	R	R
Oxidizing salts	R	R	R	R	R

Chemical - Organics	CPVC	PE	PP	PVC	PVDF
Acids	R	R	R	R	R
Acid anhydrides	NR	L	L	R	L
Alcohols-glycols	L	L	R	NR	R
Esters / ketones / ethers	NR	L	L	NR	L
Hydrocarbons – aliphatic	R	L	L	L	R
Hydrocarbons – aromatic	NR	NR	NR	NR	R
Hydrocarbons – halogenated	L	NR	NR	L	R
Natural gas	L	R	R	L	R
Synthetic gas	NR	L	L	NR	R
Oils	L	L	L	L	R

R = Recommended L = Limited Use NR = Not Recommended

Environmental Soundness

Every thermoplastic piping product material is recycled and used in the manufacturing process and is completely recyclable after the end of product life. Also, the cumulative energy required to manufacture, install, and transport plastic piping systems is much less than that of most non-plastic piping systems.

Cost Comparison of Installed Piping Systems

Most independent studies show that plastic piping systems in industrial, residential, and commercial applications are 20 percent to 50 percent less costly to install and maintain.

ENGINEERING DESIGN CONSIDERATIONS

The accepted engineering practices when designing with thermoplastic piping are similar to those when designing with other piping materials. However, design engineers should be aware of some unique properties to ensure an effective and long-lasting plastic piping installation. These properties are:

- Chemical resistance
- Pipe and system pressure ratings
- Temperature limits
- Temperature/pressure relationship
- Expansion and contraction
- Support spacing

Chemical Resistance

Plastics in general have excellent chemical resistance. This quality is one of the major reasons why plastics have made inroads in many piping applications. Generally, all plastic piping can handle aggressive water systems, including salt water. Most plastic products also handle mild acids and caustics. Piping and resin manufacturers have tested hundreds of reagents to determine their effect on plastic piping and as a result have published chemical-resistance tables for design use, which list the plastic type plus temperature limitation for each chemical. Figure 7 shows broad general categories of chemical resistance by material.

Pipe and System Pressure Ratings

There are two basic pressure ratings of plastic piping: schedule and constant pressure. Schedule pipe has an outside diameter similar to iron pipe size, with a wall thickness that matches the wall thickness of the same size and schedule metal pipe. Most vinyl (PVC and CPVC) pipe is available in both Schedule 40 and Schedule 80 dimensions. Schedule pipe pressure ratings vary with pipe diameter. Schedule pipe pressure ratings normally decrease as the pipe diameter increases.

Table 1 Comparisons of SDR PVC pipe pressure ratings at 73°F

SDR Rating	Pressure Rating (psi)	Bar Rating (atm)
13.5	315	21.4
17.0	250	17.0
21.0	200	13.6
26.0	160	10.9
32.5	125	8.5
41.0	100	6.8

Standard dimension ratio (SDR) pipe is based on iron pipe size outside diameters, with pipe wall thicknesses varying to allow the pipe to have a constant pressure rating for all diameters. Commonly used SDR ratings and corresponding pressure ratings are shown in Table 1. Most metric piping is also constant pressure rated, but instead of pounds per square inch (psi), atmosphere or bar ratings are used.

Plastic pipe fittings have similar pressure ratings as the pipe. However, some molded fitting manufacturers have lowered the pressure capability of their fittings in comparison to pipe for critical applications. One of the limiting pressure ratings in plastic piping systems is the 150-psi working pressure rating of valves, unions, and flanges. However, several plastic valve manufacturers now offer valves rated at 235-psi working pressure.

Direct threading of thermoplastic piping is accomplished using only proper threading equipment. Schedule 80 and Schedule 120 pipe are the only plastic piping materials suitable for threading. With vinyl piping, direct threading reduces working pressure by 50 percent. With other materials, the pressure rating is reduced to 20 psi or less. If threaded thermoplastic piping systems must be used, increased working pressures can be obtained using transition fittings such as molded unions and adapters.

Temperature Limits

Although some engineered thermoplastics can handle temperatures exceeding 400°F, they are not readily available in commonly used piping systems. The maximum temperature limits for commonly used plastic piping are shown in Table 2. The lower limit for plastic pipe is 0°F or less; however, when thermoplastic piping will be exposed to temperatures below freezing, the installation must protect the pipe surface from heavy impact to accommodate a decline in the pipe material's shear strength.

Table 2 Maximum temperature limits for plastic piping

Pipe Type	Temperature Limit (°F)
PVC	140
PE	160
PP	180
CPVC	210
PVDF	285

Table 3 Comparison of Schedule 80 pipe pressure ratings (psi) at 73°F

Nominal Pipe Size (in)	PVC/CPVC	PE (SDR 11)[a]	PP[b]	PVDF
½	850	160	410	580
¾	690	160	330	470
1	630	160	310	430
1½	470	160	230	320
2	400	160	200	270
3	370	160	190	250
4	320	160	160	220
6	280	160	140	190
8	250	160	N/A	N/A
10	230	160	N/A	N/A
12	230	160	N/A	N/A

[a] PE is not Schedule 80.
[b] Pipe pressure ratings shown are pipe manufacturer's values.

Table 4 Temperature correction factors for piping

Operating Temperature (°F)	CPVC	PE	PP	PVC	PVDF
70	1.00	1.00	1.00	1.00	1.00
80	1.00	0.90	0.97	0.88	0.95
90	0.91	0.84	0.91	0.75	0.87
100	0.82	0.78	0.85	0.62	0.80
110	0.72	0.74	0.80	0.50	0.75
120	0.65	0.63	0.75	0.40	0.68
130	0.57	0.57	0.68	0.30	0.62
140	0.50	0.50	0.65	0.22	0.58
150	0.42	D/O	0.57	NR	0.52
160	0.40	D/O	0.50	NR	0.49
170	0.29	D/O	0.26	NR	0.45
180	0.25	D/O	D/O	NR	0.42
200	0.20	NR	NR	NR	0.36
210	0.15	NR	NR	NR	0.33
220	NR	NR	NR	NR	0.30
240	NR	NR	NR	NR	0.25

D/O = Drainage only
NR = Not recommended

Table 5 Maximum operating pressure (psi) of valves*, unions*, and flanges

Operating Temperature (°F)	CPVC	PP	PVC	PVDF
73-100	150	150	150	150
110	140	140	135	150
120	130	130	110	150
130	120	118	75	150
140	110	105	50	150
150	100	93	NR	140
160	90	80	NR	133
170	80	70	NR	125
180	70	50	NR	115
190	60	NR	NR	106
200	50	NR	NR	97
220	NR	NR	NR	67
240	NR	NR	NR	52

* Valve and union pressure ratings may vary with each manufacturer.
NR = Not recommended

Table 6 y factor for plastic pipe types

Material	y Factor
PVC	0.360
CPVC	0.456
PP	0.600
PVDF	0.948
PE	1.000

Temperature/Pressure Relationship

Thermoplastic piping materials decrease in tensile strength as temperature increases. This characteristic must be considered when designing plastic piping systems. The correction factor for each temperature and material is calculated by an established formula. To determine the maximum suggested design pressure at a given temperature, multiply the base pressure by the correction factor. Use Tables 3 and 4 to determine the maximum pressure rating of 3-inch PP Schedule 80 pipe at 120°F. Use the pressure rating of 3-inch PP pipe at ambient, which equals 190 psi, and multiply by 0.75, or 142.5 psi.

The temperature correction factors for valves, unions, and flanges are different than those for pipe (see Table 5).

Thermal Expansion and Contraction

Compared to non-plastic piping, thermoplastics have relatively higher coefficients of thermal expansion and contraction. For this reason, it is important to consider thermal elongation and contraction when designing thermoplastic piping systems. Use the following formula and the y values found in Table 6 to calculate the expansion or contraction of plastic pipe.

$$\Delta L = y\frac{T_1 - T_2}{10} \times \frac{L}{100}$$

where

ΔL = Expansion in pipe (inches)
y = Constant factor (inches/10°F/100 feet, see Table 6)
T_1 = Maximum temperature (°F)
T_2 = Minimum temperature (°F)
L = Length of pipe run (feet)

Example: How much expansion will result in 300 feet of PVC pipe installed at 50°F and operating at 125°F? Using the formula above:

$$\Delta L = 0.36\frac{(125 - 50)}{10} \times \frac{300}{100}$$

Thus, ΔL = 8.1 inches.

Expansion Loops and Offsets

Forces resulting from thermal expansion and contraction can be reduced or eliminated by providing piping offsets, expansion loops, or expansion joints. The preferred method of handling expansion and contraction is to use offset and/or expansion loops. Expansion joints require little space, but are limited in elongation length and can be a maintenance and repair issue. As a rule of thumb, if the total temperature change is greater than 30°F, compensation for thermal expansion should be considered.

Support Spacing

The tensile and compressive strengths of plastic piping are less than those of metal piping. Consequently, plastic piping requires additional pipe support. In addition, as temperature increases, tensile strength decreases, requiring additional support. At very elevated temperatures, continuous support may be required. Tables 7 and 8 list the support spacing of Schedule 80 piping and pipe support spacing corrections for fluids with specific gravities greater than 1.0.

JOINING AND TESTING METHODS

Plastic and non-plastic installation, testing, and repair techniques have some distinctive differences. However, always use good practices similar to other piping materials. For example:

- Always have a slow-opening valve at the pump discharge.
- Provide for proper air relief and vacuum break at high points.
- Follow specific manufacturer's installation and safety manual.

- Train installers handling the piping material for the first time.
- Use appropriate piping joining tools and accessories.
- Ensure that installed piping is as stress-free as possible.
- Eliminate air from the piping system before testing and startup.

Joining Methods

Before joining any plastic piping products, always perform the following:

- Inspect the products to be joined to ensure that no cracks, gouges, warping, or other imperfections are present.
- Make certain the fitting socket and outside pipe diameter fit as described by the manufacturer.
- Cut all pipe squarely, debur all cuts, and bevel where applicable.
- Thoroughly clean all piping products before joining.
- Keep piping products to be joined at similar temperatures when solvent cementing or heat fusing.
- Use appropriate joining methods (see Table 9).
- Be knowledgeable of the manufacturer's installation procedures.

Testing

Test all plastic piping systems hydrostatically prior to full service unless the manufacturer states otherwise. The exceptions are for specially formulated plastic piping systems designed to transport compressed air or gas.

When testing:

- Test all piping before putting it into service.
- Do not test with air/gas unless manufacturer approves.
- Make sure air is removed from lines to be tested.
- Make certain solvent-welded joints are fully cured before testing.
- Test both carrier and containment pipe in dual-containment piping.
- Minimize surge pressures when filling system to be tested.
- Test pressure should be no more than 1½ times the designed maximum system operating pressure or at the rating of the lowest-rated system component.
- Test belowground piping before completely backfilling. (Leave all joints exposed during testing.)
- If testing at high pressures, only the personnel required for the test should be present.

Table 7 Support spacing of Thermoplastic Industrial Piping Systems (TIPS) Schedule 80 pipe (feet)*

Nominal Pipe Diameter (in)	CPVC			PP			PVC			PVDF		
	60°F	100°F	140°F	60°F	100°F	140°F	60°F	100°F	140°F	60°F	100°F	140°F
½	5½	5	4½	4	3	2	5	4½	2½	4½	4½	2½
¾	6	5½	4½	4	3	2	5½	4½	2½	4½	4½	3
1	6½	6	5	4½	3	2	6	5	3	5	4¾	3
1½	7	6½	5½	5	3½	2	6½	5½	3½	5½	5	3
2	7½	7	6	5	3½	2	7	6	3½	5½	5¼	3
3	9	8	7	6	4	2½	8	7	4	6½	5¾	4
4	10	9	7½	6	4½	3	9	7½	4½	7¼	6	4
6	11	10	9	6½	5	3	10	9	5	8½	7	5
8	11	11	10	7	5½	3½	11	9½	5½	9½	7½	7

* Listings show spacing (feet) between supports. Pipe is normally in 20-foot lengths. Use continuous support for spacing less than 3 feet.

Table 8 Pipe support spacing corrections with specific gravities greater than 1.0*

Specific Gravity	Correction Factor
1.0	1.00
1.1	0.98
1.2	0.96
1.4	0.93
1.6	0.90
2.0	0.85
2.5	0.80

* Above data is for un-insulated lines. For insulated lines, reduce spans to 70 percent of values shown.

Table 9 Joining methods by plastic piping material

Joining Method	ABS	CPVC	PE	PEX	PP	PVC	PVDF
Flanging	X	X	X	X	X	X	X
Solvent cementing	X	X				X	
Heat fusion			X		X		X
Mechanical— pressure	X	X	X	X	X	X	
Mechanical— drainage		X			X	X	X
Mechanical—push fit		X	X	X		X	X
Mechanical—quick connect					X		X
Mechanical—transitions	X	X	X	X	X	X	X
Direct threading (Schedule 80)		X			X	X	X

CONCLUSION

For the past four decades, thermoplastics have been the fastest growing piping material in the world. This material has been successful due to its environmental soundness, durability, easy and safe installation, and cost-effectiveness. Plumbing engineers should be aware of plastics' unique properties to ensure effective and long-lasting installations. PSD

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