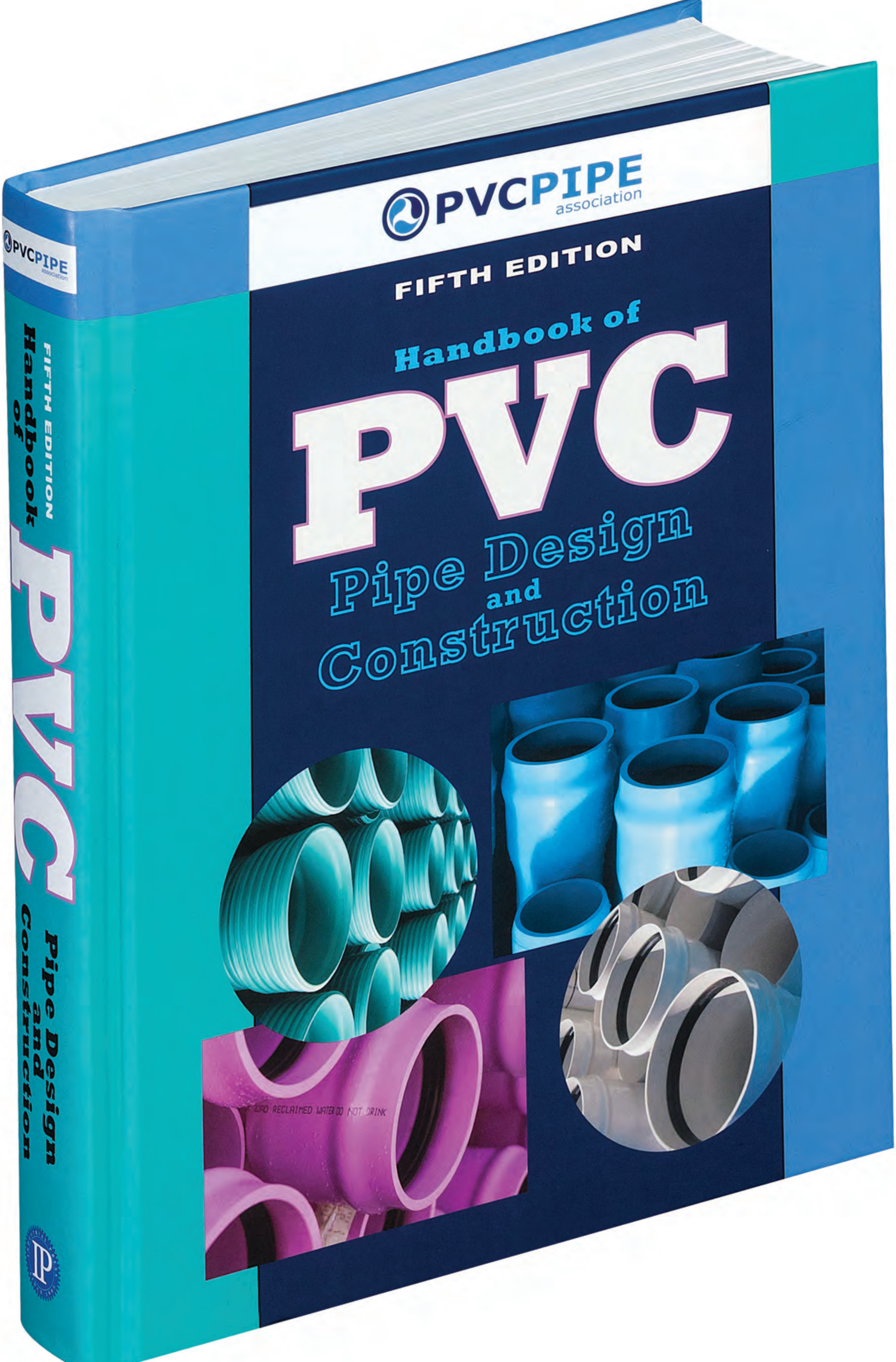
PVCPIPE association
FIFTH EDITION
Handbook of
PVC
Pipe Design
and
Construction
RECLAIMED WATER DO NOT DRINK
PVCPIPE association
FIFTH EDITION
Handbook of
PVC
Pipe Design
and
Construction

CHAPTER 3

Resistance to Aggressive Environments

Corrosion
•
Chemical Attack
•
Permeation
•
Biological Attack
•
Weathering
•
Abrasion
•
Soil Movement
•
Repetitive Fatigue

Table of Contents

3.1 Notation

P = partial pressure (psi)
P_o = saturated vapor pressure (psi)

3.2 Introduction

Determination of a piping system's true cost requires evaluating the system over its life. In addition to the initial costs of materials and installation, the long-term costs associated with operation, maintenance, and repair/replacement must be considered. The ability of a pipe or fitting material to resist deterioration, especially corrosion, is a critically important part of cost analysis. For both water mains and sewer lines, the long-term effects of corrosion must be considered, as premature replacement escalates infrastructure maintenance costs for the end user.

When reliability and durability are evaluated against other piping materials, PVC excels. However, successful long-term performance of PVC pipe depends upon proper system design, installation, and application. It is therefore important that engineers, contractors, and operators understand fully the response of PVC pipe to aggressive environments.

3.3 Corrosion

3.3.1 General Information

Corrosion causes numerous problems and expenses for both pressure and nonpressure piping systems throughout the world. Hundreds of millions of dollars are spent each year on maintenance, repair, and replacement of corrosion-damaged pipelines. Additional millions of dollars are spent on design, maintenance, and installation of piping systems that resist corrosion.

While monetary consequences are important, the implications of corrosion extend beyond economic considerations. The ability to control corrosion in both pressure and nonpressure systems can contribute greatly to the health and safety of the public. When the effects of corrosion compromise the pressure of a system, there is a potential for contaminated liquid backflow and inadequate flow for fire protection. Likewise, with regard to sewers, when corrosion damage results in leakage of a noxious substance, the environment and ultimately the public incur damages.

Results of tests conducted by a utility in Alberta, Canada, on 25-year-old PVC water pipes showed no significant deterioration of pipe properties. In a Water Research Foundation (WRF) study, the model projected that water utilities could expect a minimum service life of 100 years from PVC pipe.

3.3.2 External Corrosion

It has long been known that many materials buried in the earth undergo corrosion, the rate and degree of which depends upon the properties of the material and the environment in which it is installed. External corrosion is the leading cause of premature piping system failure due to degradation in material strength and/or by localized pitting of the pipeline or its appurtenances.

While corrosion is most often the cause of failure, it is not always recognized as such. Instead, incorrect reasons such as expansive soils and frost heave are cited for failure.

A number of publications are available on corrosion and the designing of pipelines to resist corrosion. These publications include a series by the National Association of Corrosion Engineers entitled Managing Corrosion with Plastics (see Uni-Bell's UNI-PUB-7, External Corrosion of Underground Water Distribution Piping Systems).

3.3.3 Internal Corrosion

Internal corrosion of water distribution systems can result in three distinct types of problems: (1) failure of the pipe itself due to leakage; (2) loss of hydraulic capacity as a result of corrosion byproduct build up; and (3) adverse change in water quality due to leaching of corrosion products into the water or the corrosion products' support of bacteria growth. Such changes can result in water quality violations and compromise water safety, with corrosion buildups and mineral precipitates harboring bacteria and inhibiting effective disinfection. These and many other findings, as well as methods for inhibiting internal corrosion in a variety of materials, can be found in the publication entitled Internal Corrosion of Water Distribution Systems, a cooperative research report published in 1985 by the AWWA Research Foundation and the Engler-Bunte Institute of Karlsruhe, Germany.

Internal corrosion due to sulfide generation in sanitary sewers has also resulted in piping failures. A description of the vast nature of this problem with recommended solutions is available in a paper entitled Case Histories of Sulfide Corrosion, by Schafer, Horner, and Witzgall, which was published in the 1990 Proceedings of the American Society of Civil Engineers (ASCE) International Conference on Pipeline Design and Installation. Furthermore, in 1991 the U.S. Environmental Protection Agency, as a result of the Water Quality Act of 1987, composed a report to Congress on the control and prevention of corrosion induced by hydrogen sulfide.

3.3.4 PVC Pipe and Fittings

PVC pipe and fittings are immune to nearly all types of corrosion experienced in underground piping systems. Soluble encrustants (such as calcium carbonate) found in some water supplies do not readily precipitate onto the smooth walls of PVC pipes. Since PVC pipe does not corrode, there is no tuberculation caused by corrosion byproducts, and no tuberculation means there is no reduction in flow areas or flow coefficients as PVC piping systems age. The long-term result of PVC pipe's resistance to tuberculation is reduced cost for operations and maintenance.

Since PVC is a nonconductor, both galvanic and electrochemical effects are nonexistent in PVC pipe and fittings. PVC suffers no damage from attack of normal or corrosive soils and is not affected by sulfuric acid in the concentrations found in sanitary sewer systems. As a result, no linings, coatings, or cathodic protection are required when PVC pipe is used, resulting in cost savings for construction and future maintenance.

Different water and sewer pipe products provide corrosion resistance in varying degrees depending on application and environment. For this reason, corrosion must be considered when piping products are selected. Because corrosive attack can be anticipated in most underground systems, PVC pipe's corrosion resistance provides considerable savings in the form of reduced operating costs and longer system life.

3.4 Chemical Attack

3.4.1 General Information

A pipe system may be subject to a number of aggressive chemical exposures, accidental or otherwise. Resistance of PVC pipe and elastomeric gaskets to attack by chemical agents has been determined through years of research and field experience, demonstrating its ability to endure a broad range of both acidic and caustic environments. In general, PVC piping systems are not adversely affected by chemicals found in typical potable water and sanitary sewer systems.

3.4.2 Factors Affecting Resistance

Chemical reactions can be very complex; there are so many factors affecting the reaction of a piping system to chemical attack that it is impossible to construct charts to cover all possibilities. Some of the factors affecting chemical resistance are:

- temperature
- chemical (or mixture of chemicals) present
- concentration of chemicals
- duration of exposure
- frequency of exposure
- PVC compound (or elastomeric compound) present
- geometry of piping system.

3.4.3 Oxidation

Disinfection is an important step in providing safe drinking water. Chemical disinfectants are added to water systems to destroy microorganisms that can cause disease in humans. The EPA Surface Water Treatment Rule requires water utilities to disinfect water obtained from surface water supplies or groundwater sources influenced by surface water. The most common chemical disinfectants are chlorine (sodium hypochlorite), chloramines, and chlorine dioxide.

There are two modes of disinfection—primary and secondary. Primary disinfection achieves the desired level of microorganism kill or inactivation; secondary disinfection maintains a disinfectant residual in the finished water that prevents regrowth of microorganisms throughout the pipe distribution system.

It has been established that some plastic pipe materials are susceptible to oxidative degradation in the presence of common water disinfectants. Even at low concentrations, these disinfectants can oxidize some pipe materials and shorten a pipe's performance life.

PVC pipe has very good resistance to oxidation by disinfectants. There is no record of oxidation-induced failure in PVC water distribution pipes. The resistance of PVC pipes to water disinfectants has been confirmed through accelerated aging studies: When assessed according to the rigorous aging tests of International Organization for Standardization (ISO) 4433 (8 ppm ClO_2 and 40ºC), PVC pipes exhibit very low sensitivity to oxidizing agents.

PVC pipe mechanical properties, including elongation at break, were not altered appreciably by aggressive ISO 4433 test conditions and have been judged suitable according to this standard. After being subjected to the aggressive conditions of ISO 4433, PVC pipes experienced no loss in thermal stability when tested by dehydrochlorination (DHC), and their thermal stability was further confirmed by thermo gravimetric analysis (TGA). Likewise, measurements of viscosity index showed no reduction in PVC's molecular weight.

At normal temperatures, no attack on PVC pipe was registered in the ISO 4433 testing, even with a relatively high concentration of ClO_2. A 2,000-hour (85-day) test with both PVC and high density polyethylene (HDPE) pipes showed no decrease in PVC elongation compared to a 70 percent decrease for HDPE. This decrease in elongation indicates significant material degradation.

Resistance to oxidative degradation makes PVC the preferred plastic piping material.

3.4.4 PVC Pipe and Fittings

Experience has shown that PVC pipe and fittings are resistant to chemicals generally found in water and sewer systems. The chemical resistance information for PVC pipe listed in Table 3.1 is based on short-term immersion of unstressed strips of PVC in the listed chemicals (usually undiluted). While these resistance data may be useful in assessing the suitability of PVC under specific or unusual operating environments, they are only a guide for estimating PVC's response to chemicals. For critical applications it is recommended that testing be performed under conditions that approximate anticipated field conditions.

Table 3.1 is not intended to provide design criteria for PVC sewer pipes that are exposed to chemicals only occasionally or to chemicals that have been diluted by wastewater.

Table 3.1 is compiled from multiple industry sources. The National Association of Corrosion Engineers publication Corrosion Data Survey, Nonmetals Section is an additional source of information on the chemical resistance of PVC pipe.

Table 3.1 Chemical resistance* of PVC pipe

Chemical	73°F (23°C)	140°F (60°C)	Chemical	73°F (23°C)	140°F (60°C)
Acetaldehyde	N	N	Alcohol, propyl (1-propanol)	R	R
Acetaldehyde, aq 40%	C	N	Alcohol, propargyl	R	R
Acetic acid, 25%	R	R	Allyl chloride	N	N
Acetic acid, 60%	R	N	Aluminum fluoride	R	N
Acetic acid, 85%	R	N	Alums (except aluminum fluoride)	R	R
Acetic acid, glacial	R	N	Ammonia, gas	R	R
Acetic acid, vapor	R	R	Ammonia, liquid	N	N
Acetic anhydride	N	N	Ammonium dichromate	R	N
Acetone	N	N	Ammonium salts (except ammonium dichro-mate)	R	R
Acetylene	N	N	Ammonium fluoride, 10%	R	R
Acetyl chloride	N	N	Ammonium fluoride, 25%	R	C
Acetylnitrile	N	N	Amyl acetate	N	N
Acrylonitrile	N	N	Amyl chloride	N	N
Acrylic acid	N	N	Aniline	N	N
Adipic acid	R	R	Aniline chlorohydrate	N	N
Alcohol, allyl	R	C	Aniline hydrochloride	N	N
Alcohol, amyl	N	N	Anthraquinone	R	R
Alcohol, benzyl	N	N	Anthraquinone sulfonic acid	R	R
Alcohol, butyl (n-butanol)	R	R	Antimony trichloride	R	R
Alcohol, diacetone	N	N	Aqua regia	C	N
Alcohol, ethyl (ethanol)	R	R	Arsenic acid, 80%	R	R
Alcohol, hexyl (hexanol)	R	R	Aryl-sulfonic acid	R	R
Alcohol, isopropyl (2-propanol)	R	R			
Alcohol, methyl (methanol)	R	R			

*R = generally resistant; C = less resistant than R but still suitable for some conditions; N = not resistant

This table is meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data are provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

Table 3.1 Chemical resistance of PVC pipe (*continued*)

Chemical	73°F (23°C)	140°F (60°C)	Chemical	73°F (23°C)	140°F (60°C)
Barium nitrate	R	N	Butyl phenol	R	N
Barium salts (except barium nitrate)	R	R	Butylene, liquid	R	R
			Butynediol	R	N
Beer	R	R	Butyric acid	R	N
Beet sugar liquor	R	R			
Benzaldehyde, 10%	R	N	Cadmium cyanide	R	R
Benzene (benzol)	N	N	Calcium bisulfide	N	N
Benzene sulfonic acid, 10%	R	R	Calcium salts (except calcium bisulfide)	R	R
Benzene sulfonic acid, >10%	N	N	Calcium hypochlorite, 30%	R	R
Benzoic acid	R	R	Calcium hydroxide	R	R
Black liquor – paper	R	R	Calcium nitrate	R	R
Bleach, 12% active chlorine	R	R	Calcium oxide	R	R
			Calcium sulfate	R	R
Bleach, 5% active chlorine	R	R	Camphor	R	N
			Cane sugar liquors	R	R
Borax	R	R	Carbon dioxide	R	R
Boric acid	R	R	Carbon dioxide, aq	R	R
Brine	R	R	Carbon disulfide	N	N
Bromic acid	R	R	Carbon monoxide	R	R
Bromine, aq	R	R	Carbitol	R	N
Bromine, liquid	N	N	Carbon tetrachloride	R	N
Bromine, gas, 25%	R	R	Carbonic acid	R	R
Bromobenzene	N	N	Castor oil	R	R
Bromotoluene	N	N	Caustic potash (potassium hydroxide), 50%	R	R
Butadiene	R	R			
Butane	R	R	Caustic soda (sodium hydroxide), < 40%	R	R
Butyl acetate	N	N			
Butyl stearate	R	N	Cellosolve	R	N

Table 3.1 Chemical resistance* of PVC pipe (*continued*)

Chemical	73°F (23°C)	140°F (60°C)	Chemical	73°F (23°C)	140°F (60°C)
Cellosolve acetate	R	N	Corn oil	R	R
Chloral hydrate	R	R	Corn syrup	R	R
Chloramine, dilute	R	N	Cottonseed oil	R	R
Chloric acid, 20%	R	R	Creosote	N	N
Chlorine, gas, dry	C	N	Cresol, 90%	N	N
Chlorine, gas, wet	N	N	Cresylic acid, 50%	R	R
Chlorine, liquid	N	N	Croton aldehyde	N	N
Chlorine water	R	R	Crude oil, sour	R	R
Chloroacetic acid, 50%	R	R	Cupric salts, aq	R	R
Chloroacetyl chloride	R	N	Cyclohexane	N	N
Chlorobenzene	N	N	Cyclohexanol	N	N
Chlorobenzyl chloride	N	N	Cyclohexanone	N	N
Chloroform	N	N			
Chloropicrin	N	N	Detergents, aq	R	R
Chlorosulfonic acid	R	N	Dextrin	R	R
Chromic acid, 10%	R	R	Dextrose	R	R
Chromic acid, 30%	R	R	Dibutoxyethyl phthalate	N	N
Chromic acid, 40%	R	C	Dibutyl phthalate	N	N
Chromic acid, 50%	N	N	Dibutyl sebacate	R	N
Chromium potassium sulfate	R	N	Dichlorobenzene	N	N
			Dichloroethylene	N	N
Citric acid	R	R	Diesel fuels	R	R
Coconut oil	R	R	Diethylamine	N	N
Coffee	R	R	Diethyl ether	R	N
Coke oven gas	R	R	Diglycolic acid	R	R
Copper acetate	R	N	Dimethyl formamide	N	N
Copper salts, aq	R	R	Dimethylamine	R	R

*R = generally resistant; C = less resistant than R but still suitable for some conditions; N = not resistant

This table is meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data are provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

Table 3.1 Chemical resistance of PVC pipe (*continued*)

Chemical	73°F (23°C)	140°F (60°C)	Chemical	73°F (23°C)	140°F (60°C)
Disodium phosphate	R	R	Glucose	R	R
Dioxane-1,4	N	N	Glue, animal	R	R
			Glycerine (glycerol)	R	R
Ether	N	N	Glycolic acid	R	R
Ethyl ether	N	N	Grape sugar	R	R
Ethyl halides	N	N	Green liquor, paper	R	R
Ethylene glycol	R	R			
Ethylene halides	N	N	Heptane	R	R
Ethylene oxide	N	N	Hexane	R	N
			Hexanol	R	R
Fatty acids	R	R	Hydraulic oil	R	N
Ferric salts	R	R	Hydrazine	N	N
Fish oil	R	R	Hydrobromic acid, 20%	R	R
Fluorine, dry gas	R	N	Hydrochloric acid	R	R
Fluorine, wet gas	R	N	Hydrocyanic acid	R	R
Fluoroboric acid	R	R	Hydrofluoric acid, 30%	R	N
Fluorosilicic acid, 50%	R	R	Hydrofluoric acid, 50%	R	N
Formaldehyde	R	R	Hydrofluoric acid, 100%	N	N
Formic acid	R	N	Hydrofluorosilicic acid	R	R
Freon—F11, F12, F113, F114	R	R	Hydrogen	R	R
Freon—F21, F22	N	N	Hydrogen cyanide	R	R
Fructose	R	R	Hydrogen fluoride	N	N
Furfural	N	N	Hydrogen peroxide, 50%	R	R
			Hydrogen peroxide, 90%	R	R
Gallic acid	R	R	Hydrogen phosphide	R	R
Gas, coal, manufactured	N	N	Hydrogen sulfide, aq	R	R
Gas, natural, methane	R	R	Hydrogen sulfide, dry	R	R
Gasoline	R	R	Hydroquinone	R	R
Gelatin	R	R	Hydroxylamine sulfate	R	R

Table 3.1 Chemical resistance* of PVC pipe (*continued*)

Chemical	73°F (23°C)	140°F (60°C)	Chemical	73°F (23°C)	140°F (60°C)
Hypochlorous acid	R	R	Magnesium salts	R	R
			Maleic acid	R	R
Iodine, aq, 10%	N	N	Malic acid	R	R
			Manganese sulfate	R	R
Jet fuels, JP-4 and JP-5	R	R	Mercuric salts	R	R
			Mercury	R	R
			Methane	R	R
Kerosene	R	R	Methoxyethyl oleate	R	N
Ketchup	R	N	Methyl acetate	N	N
Ketones	N	N	Methyl amine	N	N
Kraft paper liquor	R	R	Methyl bromide	N	N
			Methyl cellosolve	N	N
Lactic acid, 25%	R	R	Methyl chloride	N	N
Lactic acid, 80%	R	N	Methyl chloroform	N	N
Lard oil	R	R	Methyl ethyl ketone	N	N
Lauric acid	R	R	Methyl isobutyl carbinol	N	N
Lauryl acetate	R	R	Methyl isobutyl ketone	N	N
Lauryl chloride	R	R	Methyl isopropyl ketone	N	N
Lead salts	R	R	Methyl methacrylate	R	N
Lime sulfur	R	N	Methyl sulfate	R	N
Linoleic acid	R	R	Methyl sulfuric acid	R	R
Linoleic oil	R	R	Methylene bromide	N	N
Linseed oil	R	R	Methylene chloride	N	N
Liqueurs	R	R	Methylene iodide	N	N
Lithium salts	R	R	Milk	R	R
Lubricating oils	R	R	Mineral oil	R	R

*R = generally resistant; C = less resistant than R but still suitable for some conditions; N = not resistant

This table is meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data are provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

Table 3.1 Chemical resistance of PVC pipe (*continued*)

Chemical	73°F (23°C)	140°F (60°C)	Chemical	73°F (23°C)	140°F (60°C)
Molasses	R	R	Palmitic acid, 10%	R	R
Monochloroacetic acid	R	R	Palmitic acid, 70%	R	N
Monochlorobenzene	N	N	Paraffin	R	R
Monoethanolamine	N	N	Pentane	C	C
Motor oil	R	R	Peracetic acid, 40%	R	N
			Perchloric acid, 15%	R	N
Naphtha	R	R	Perchloric acid, 70%	R	N
Naphthalene	N	N	Perchloroethylene	C	C
Natural gas	R	R	Perphosphate	R	N
Nickel acetate	R	N	Phenol	R	N
Nickel salts	R	R	Phenylhydrazine	N	N
Nicotine	R	R	Phosphoric acid	R	R
Nicotinic acid	R	R	Phosphoric anhydride	R	N
Nitric acid, 0 to 40%	R	R	Phosphorus, red	R	N
Nitric acid, 50%	R	C	Phosphorus, yellow	R	N
Nitric acid, 70%	R	N	Phosphorus pentoxide	R	N
Nitric acid, 100%	N	N	Phosphorus trichloride	N	N
Nitrobenzene	N	N	Photographic chemicals, aq	R	R
Nitroglycerine	N	N	Phthalic acid	C	C
Nitroglycol	N	N	Picric acid	N	N
Nitrous acid, 10%	R	R	Plating solutions, metal	R	R
Nitrous oxide, gas	R	N	Potash	R	R
			Potassium amyl xanthate	R	N
Oleic acid	R	R	Potassium iodide	R	N
Oleum	N	N	Potassium salts (except potassium iodide)	R	R
Olive oil	R	R	Potassium permanganate, 10%	R	R
Oxalic acid	R	R			
Oxygen, gas	R	R			
Ozone, gas	R	R			

Table 3.1 Chemical resistance* of PVC pipe (*continued*)

Chemical	73°F (23°C)	140°F (60°C)	Chemical	73°F (23°C)	140°F (60°C)
Potassium permanganate, 25%	R	N	Stearic acid	R	R
			Stoddard solvent	N	N
Propane	R	R	Succinic acid	R	R
Propylene dichloride	N	N	Sugars, aq	R	R
Propylene oxide	N	N	Sulfamic acid	N	N
Pyridine	N	N	Sulfate & sulfite liquors	R	R
Pyrogallic acid	R	N	Sulfur	R	R
			Sulfur dioxide, dry	R	R
Rayon coagulating bath	R	R	Sulfur dioxide, wet	R	N
			Sulfur trioxide, gas, dry	R	R
Salicylic acid	R	R	Sulfur trioxide, wet	R	N
Salicylaldehyde	N	N	Sulfuric acid, up to 80%	R	R
Selenic acid, aq.	R	R	Sulfuric acid, 90 to 93%	R	N
Silicic acid	R	R	Sulfuric acid, 94 to 100%	N	N
Silicone oil	R	N	Sulfurous acid	R	R
Silver salts	R	R			
Soaps	R	R			
Sodium chlorate	R	N	Tall oil	R	R
Sodium chlorite	N	N	Tannic acid	R	R
Sodium hypochlorite	R	N	Tanning liquors	R	R
Sodium salts, aq (except sodium chlorate, sodium chlorite, and sodium hypochlorite)	R	R	Tar	N	N
			Tartaric acid	R	R
			Terpineol	C	C
Stannic chloride	R	R	Tetrachloroethane	C	C
Stannous chloride	R	R	Tetraethyl lead	R	N
Starch	R	R	Tetrahydrofuran	N	N

*R = generally resistant; C = less resistant than R but still suitable for some conditions; N = not resistant

This table is meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data are provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

Table 3.1 Chemical resistance of PVC pipe (*continued*)

Chemical	73°F (23°C)	140°F (60°C)	Chemical	73°F (23°C)	140°F (60°C)
Tetralin	N	N	Urea	R	R
Tetrasodium	R	R	Urine	R	R
Thionyl chloride	N	N			
Thread cutting oils	R	N	Vaseline	N	N
Titanium tetrachloride	C	N	Vegetable oils	R	R
Toluene	N	N	Vinegar	R	R
Tomato juice	R	R	Vinyl acetate	N	N
Transformer oil	R	R			
Tributyl citrate	R	N	Water, deionized	R	R
Tributyl phosphate	N	N	Water, distilled	R	R
Trichloroacetic acid	R	R	Water, salt	R	R
Trichloroethylene	N	N	Whiskey	R	R
Triethanolamine	R	N	White liquor	R	R
Triethylamine	R	R	Wines	R	R
Trimethyl propane	R	N			
Trisodium phosphate	R	R	Xylene	N	N
Turpentine	R	R	Zinc salts	R	R

3.4.5 Gaskets

Because gasket and pipe materials differ, so too does their ability to resist chemical attack. Therefore, a check of the gasket's chemical resistance should be completed independent of the pipe's. Tables 3.2 and 3.3 will aid the designer in selecting an appropriate gasket material.

In applications where exposure to harmful chemicals is frequent, of long duration, or in high concentrations, further testing is recommended.

General chemical resistance information for commonly used gasket materials is presented in Table 3.2.

The factors generally considered most important in gasket material choice are:

- *Temperature of service:* Higher temperatures increase the effect of all chemicals on elastomers. The increase varies with the elastomer and the chemical. An

Table 3.2 General chemical resistance of various gasket materials

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/NBR	Neoprene/CR
CHEMICAL GROUP	Polybutadiene, Butadiene styrene copolymer	Ethylene propylene copolymer and terpolymer	Butadiene acrylonitrile copolymer	Chloroprene polymer
GENERALLY RESISTANT TO	Most moderate chemicals wet or dry, organic acids, alcohols, ketones, aldehydes	Animal and vegetable oils, ozone, strong and oxidizing chemicals	Many hydrocarbons, fats, oils, greases, hydraulic fluids, chemicals	Moderate chemicals and acids, ozone, oils, fats, greases, many oils and solvents
GENERALLY ATTACKED BY	Ozone, strong acids, fats, oils, greases, most hydrocarbons	Mineral oils and solvents, aromatic hydrocarbons	Ozone*, ketones, esters, aldehydes, chlorinated and nitro hydrocarbons	Strong oxidizing acids, esters, ketones, chlorinated, aromatic and nitro hydrocarbons

*except PVC blends

elastomeric compound quite suitable at room temperature might fail at elevated temperatures.

- *Conditions of service:* An elastomeric compound that swells might still function well as a seal.
- *Grade of elastomer:* Many types of elastomers are available in different grades that vary greatly in chemical resistance.
- *Elastomeric compound:* Compounds designed for chemical resistance may affect mechanical properties.
- *Availability:* The pipe manufacturer should be consulted as to whether a specific elastomeric compound is available.

Table 3.2 is offered as a general guide and indication of the suitability of various elastomers used today to service the listed chemicals and fluids. Table 3.3 is a more detailed guide. The ratings are based, for the most part, on published literature of various polymer suppliers and rubber manufacturers, but in some cases they represent the considered opinion of experienced elastomer compounders.

Table 3.3 Chemical resistance* of (PVC) gasket materials

	General purpose, non-oil resistant		General purpose, oil resistant	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Acetaldehyde	N	R	N	N
Acetamide	N	R	R	C
Acetic acid, 30%	C	R	C	R
Acetic acid, glacial	N	R	N	N
Acetic anhydride	C	C	N	R
Acetone	C	R	N	C
Acetophenone	N	R	N	N
Acetyl chloride	—	—	—	N
Acetylene	C	R	C	C
Acrylonitrile	N	N	N	N
Adipic acid	—	—	R	—
Alkazene	—	N	—	N
Alum-NH_3-Cr-K	R	R	R	R
Aluminum acetate	C	R	C	C
Aluminum chloride	N	R	R	R
Aluminum fluoride	R	R	R	R
Aluminum nitrate	R	R	R	R
Aluminum phosphate	R	R	R	R
Aluminum sulfate	C	R	R	R
Ammonia anhydrous	—	R	R	R
Ammonia gas (cold)	R	R	R	R
Ammonia gas (hot)	—	C	—	C

*R = generally resistant; C = less resistant than R but still suitable for some conditions; N = not resistant

A dash indicates insufficient data to provide a rating.

This table is meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data are provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

Table 3.3 Chemical resistance* of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Ammonium carbonate	R	R	N	R
Ammonium chloride	R	R	R	R
Ammonium hydroxide	N	R	N	R
Ammonium nitrate	R	R	R	C
Ammonium nitrite	R	R	R	R
Ammonium persulfate	N	R	N	R
Ammonium phosphate	R	R	R	R
Ammonium sulfate	C	R	R	R
Amyl acetate	N	R	N	N
Amyl alcohol	C	R	C	R
Amyl borate	N	N	R	R
Amyl chloronapthalene	N	N	—	N
Amyl napthalene	N	N	N	N
Aniline	N	C	N	N
Aniline dyes	C	C	N	C
Aniline hydrochloride	N	C	C	N
Animal fats	N	C	R	C
Ansul ether	N	N	N	N
Aqua regia	N	N	—	N
Arochlor (solid)	N	N	N	N
Arsenic acid	R	R	R	R
Arsenic trichloride	—	—	R	R

*R = generally resistant; C = less resistant than R but still suitable for some conditions; N = not resistant

A dash indicates insufficient data to provide a rating.

This table is meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data are provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

Table 3.3 Chemical resistance of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Askarel	N	N	C	N
Asphalt	N	—	C	N
Barium chloride	R	R	R	R
Barium hydroxide	R	R	R	R
Barium sulfate	R	R	R	R
Barium sulfide	C	R	R	R
Beer	R	R	R	R
Beet sugar liquors	R	R	R	R
Benzaldehyde	N	R	N	N
Benzene	N	N	N	N
Benzenesulfonic acid	—	—	—	R
Benzyl alcohol	—	C	N	R
Benzyl benzoate	—	C	—	—
Benzyl chloride	—	—	N	N
Blast furnace gas	N	—	N	N
Bleach solutions	N	R	—	N
Borax	C	R	C	R
Bordeaux mixture	C	R	—	R
Boric acid	R	R	R	R
Brine	—	R	R	R
Bromine, anhydrous	—	—	—	N
Bromine trifluoride	N	N	N	N
Bromine water	—	—	—	C
Bromobenzene	N	N	N	N
Bunker oil	—	—	R	—

Table 3.3 Chemical resistance* of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Butadiene	N	N	N	C
Butane	N	N	R	R
Butter	N	R	R	C
Butyl acetate	—	C	—	N
Butyl acetyl ricinoleate	—	R	—	C
Butyl acrylate	N	N	—	—
Butyl alcohol	R	C	R	R
Butyl amine	N	N	N	N
Butyl benzoate	—	R	—	N
Butyl carbitol	—	R	R	C
Butyl cellosolve	—	R	N	C
Butyl oleate	N	C	—	N
Butyl stearate	N	C	C	—
Butylene	N	N	C	N
Butyraldehyde	N	C	N	N
Calcium acetate	—	R	C	C
Calcium bisulfite	N	N	R	R
Calcium chloride	R	R	R	R
Calcium hydroxide	R	R	R	R
Calcium hypochlorite	N	R	N	N
Calcium nitrate	R	R	R	R
Calcium sulfide	C	R	C	R

*R = generally resistant; C = less resistant than R but still suitable for some conditions; N = not resistant

A dash indicates insufficient data to provide a rating.

This table is meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data are provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

Table 3.3 Chemical resistance of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Cane sugar liquors	R	R	R	R
Carbamate	N	C	N	C
Carbitol	C	C	C	C
Carbolic acid	N	C	N	N
Carbon bisulfide	—	N	N	N
Carbon dioxide	C	C	R	C
Carbon monoxide	C	R	R	R
Carbon tetrachloride	N	N	N	N
Carbonic acid	C	R	R	R
Castor oil	R	C	R	R
Cellosolve	N	C	—	—
Cellosolve acetate	N	C	N	—
Cellulube	—	R	N	N
Chlorine (dry)	N	—	—	N
Chlorine (wet)	N	N	—	N
Chlorine dioxide	—	N	N	N
Chlorine trifluoride	N	N	N	N
Chloroacetic acid	—	C	—	—
Chloroacetone	—	R	N	C
Chlorobenzene	N	N	N	N
Chlorobromomethane	N	C	—	N
Chlorobutadiene	N	N	N	N
Chlorododecane	N	N	N	N
Chloroform	N	N	N	N
o-Chloronaphthalene	N	N	N	N
1-Chloro-1-nitroethane	N	N	N	N
Chlorosulfonic acid	N	N	N	N

Table 3.3 Chemical resistance* of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Chlorotoluene	N	N	N	N
Chrome plating solutions	N	N	N	N
Chromic acid	N	N	N	N
Citric acid	R	R	R	R
Cobalt chloride	R	R	R	R
Coconut oil	N	R	R	C
Cod liver oil	N	R	R	C
Coke oven gas	N	—	—	—
Copper acetate	—	R	C	C
Copper chloride	R	R	R	R
Copper cyanide	R	R	R	R
Copper sulfate	C	R	R	R
Corn oil	N	N	R	C
Cottonseed oil	N	R	R	C
Creosote	N	N	C	N
Cresol	N	N	N	N
Cresylic acid	N	N	N	N
Cumene	—	—	—	N
Cyclohexane	N	N	R	N
Cyclohexanol	N	N	C	R
Cyclohexanone	—	C	N	N
p-Cymene	—	—	—	N

*R = generally resistant; C = less resistant than R but still suitable for some conditions; N = not resistant

A dash indicates insufficient data to provide a rating.

This table is meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data are provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

Table 3.3 Chemical resistance of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Decalin	N	—	—	N
Decane	N	—	C	N
Denatured alcohol	R	R	R	R
Detergent solutions	C	R	R	R
Developing fluids	C	C	R	R
Diacetone	—	R	—	—
Diacetone alcohol	N	R	N	R
Dibenzyl ether	N	C	N	C
Dibenzyl sebecate	—	C	—	N
Dibutyl amine	N	N	N	N
Dibutyl ether	N	N	N	N
Dibutyl phthalate	N	R	N	N
Dibutyl sebecate	N	C	N	N
o-Dichlorobenzene	N	N	N	N
Dichloro-isopropyl ether	N	N	N	N
Didaclohexylamine	N	—	N	—
Diesel oil	N	N	R	C
Diethylamine	C	C	N	N
Diethyl benezene	N	N	N	N
Diethyl ether	N	N	N	N
Diethyl sebecate	—	C	N	N
Diethylene glycol	R	R	R	R
Diisobutylene	—	—	C	N
Diisopropyl benzene	N	N	N	N
Diisopropyl ketone	—	R	N	N
Dimethyl aniline	N	C	—	N
Dimethyl formamide	—	—	C	N

Table 3.3 Chemical resistance* of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		General purpose, oil resistant	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Dimethyl phthalate	N	C	N	N
Dinitrotoluene	N	N	N	N
Dioctyl phthalate	—	C	—	N
Dioctyl sebecate	N	C	N	N
Dioxane	—	C	—	—
Dioxolane	N	C	N	—
Dipentene	—	—	C	—
Diphenyl oxides	—	R	—	—
Dowtherm oil	N	N	—	N
Dry cleaning fluids	N	N	N	N
Epichlorohydrin	N	C	—	—
Ethane	N	N	R	C
Ethanolamine	C	C	C	C
Ethyl acetate	N	C	N	N
Ethyl acetoacetate	N	C	N	N
Ethyl acrylate	—	C	—	—
Ethyl alcohol	R	R	R	R
Ethyl benzene	N	N	N	N
Ethyl benzoate	—	C	—	—
Ethyl cellosolve	—	C	—	—
Ethyl cellulose	C	C	—	C
Ethyl chloride	C	R	R	C
Ethyl chlorocarbonate	N	—	—	N

*R = generally resistant; C = less resistant than R but still suitable for some conditions; N = not resistant

A dash indicates insufficient data to provide a rating.

This table is meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data are provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

Table 3.3 Chemical resistance of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		General purpose, oil resistant	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Ethyl chloroformate	—	—	—	N
Ethyl ether	—	N	N	N
Ethyl formate	N	C	N	C
Ethyl mercaptan	N	N	N	—
Ethyl oxalate	R	R	N	N
Ethyl pentochlorobenzene	N	N	N	N
Ethyl silicate	C	R	R	R
Ethylene	—	—	R	—
Ethylene chloride	—	N	—	—
Ethylene chlorohydrin	C	—	N	C
Ethylene diamine	C	R	R	R
Ethylene dichloride	N	N	N	N
Ethylene glycol	R	R	R	R
Ethylene oxide	—	N	N	N
Ethylene trichloride	—	N	N	N
Fatty acids	N	N	C	C
Ferric chloride	R	R	R	R
Ferric nitrate	R	R	R	R
Ferric sulfate	R	R	R	R
Fish oil	—	—	R	—
Fluorinated cyclic ethers	—	R	—	—
Fluorine (liquid)	—	N	—	—
Fluorobenzene	N	N	N	N
Fluoroboric acid	R	R	R	R
Fluorocarbon oils	—	R	—	—
Fluorolube	N	R	R	R

Table 3.3 Chemical resistance* of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Fluorosilicic acid	—	—	R	R
Formaldehyde	—	R	C	R
Formic acid	R	R	C	R
Freon 11	N	N	R	C
Freon 12	R	C	R	R
Freon 13	R	R	R	R
Freon 21	—	N	N	C
Freon 22	R	R	N	R
Freon 31	C	R	N	R
Freon 32	R	R	R	R
Freon 112	—	N	C	C
Freon 113	C	N	R	R
Freon 114	R	R	R	R
Freon 115	R	R	R	R
Freon 142b	R	R	R	R
Freon 152a	R	R	R	R
Freon 218	R	R	R	R
Freon C316	R	R	R	R
Freon C318	R	R	R	R
Freon 13B1	R	R	R	R
Freon 114B2	N	N	C	R
Freon 502	R	—	C	R
Freon TF	C	N	R	R

*R = generally resistant; C = less resistant than R but still suitable for some conditions; N = not resistant

A dash indicates insufficient data to provide a rating.

This table is meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data are provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

Table 3.3 Chemical resistance of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Freon T-WD602	C	C	C	C
Freon TMC	N	C	C	C
Freon T-P35	R	R	R	R
Freon TA	R	R	R	R
Freon TC	C	C	R	R
Freon MF	C	—	R	N
Freon BF	N	—	C	C
Fuel oil	N	N	R	C
Fumaric acid	R	—	R	C
Furan, furfuran	N	N	N	N
Furfural	N	C	N	C
Gallic acid	C	C	C	C
Gasoline	N	N	R	C
Gelatin	R	R	R	R
Glauber's salt	N	C	—	—
Glucose	R	R	R	R
Glue	R	R	R	R
Glycerin	R	R	R	R
Glycols	R	R	R	R
Green sulfate liquor	C	R	C	C
Halowax oil	N	N	N	N
n-Hexaldehyde	N	R	N	R
Hexane	N	N	R	C
n-Hexene-1	N	N	C	C
Hexyl alcohol	R	N	R	C

Table 3.3 Chemical resistance* of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Hydraulic oil (petroleum)	N	N	R	C
Hydrazine	—	R	C	C
Hydrobromic acid	N	R	N	R
Hydrochloric acid (cold) 37%	C	R	C	C
Hydrochloric acid (hot) 37%	N	N	N	N
Hydrocyanic acid	C	R	C	C
Hydrofluoric acid, anhydrous	N	C	—	—
Hydrofluoric acid (conc) (cold)	N	C	N	C
Hydrofluoric acid (conc) (hot)	N	N	N	N
Hydrofluorosilicic acid	C	R	C	N
Hydrogen gas	C	R	R	R
Hydrogen peroxide, 90%	N	N	N	—
Hydrogen sulfide, wet (cold)	N	R	N	R
Hydrogen sulfide, wet (hot)	N	R	N	C
Hydroquinone	C	—	N	—
Hypochlorous acid	C	C	N	—

*R = generally resistant; C = less resistant than R but still suitable for some conditions; N = not resistant

A dash indicates insufficient data to provide a rating.

This table is meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data are provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

Table 3.3 Chemical resistance of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Iodine pentafluoride	N	N	N	N
Iodoform	—	R	—	—
Isobutyl alcohol	C	R	C	R
Isooctane	N	N	R	C
Isophorone	—	R	N	—
Isopropyl acetate	—	R	N	N
Isopropyl alcohol	C	R	C	R
Isopropyl chloride	N	N	N	—
Isopropyl ether	N	N	C	C
Kerosene	N	N	R	N
Lacquer solvents	N	N	N	N
Lacquers	N	N	N	N
Lactic acid	R	R	R	R
Lard	N	N	R	N
Lavender oil	N	N	C	N
Lead acetate	—	R	C	C
Lead nitrate	R	R	R	R
Lead sulfamate	C	R	C	R
Lime bleach	R	R	R	C
Lime sulfur	N	R	N	R
Lindol	—	R	—	N
Linoleic acid	—	N	C	N
Linseed oil	N	C	R	C
Liquefied petroleum gas	N	N	R	C

Table 3.3 Chemical resistance* of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Lubricating oils (petroleum)	N	N	R	C
Lye	C	R	C	C
Magnesium chloride	R	R	R	R
Magnesium hydroxide	C	R	C	R
Magnesium sulfate	C	R	R	R
Maleic acid	C	N	—	—
Maleic anhydride	C	N	—	—
Malic acid	C	N	R	C
Mercuric chloride	R	R	R	R
Mercury	R	R	R	R
Mesityl oxide	N	C	N	N
Methane	N	N	R	C
Methyl acetate	N	C	N	C
Methyl acrylate	N	C	N	C
Methyl alcohol	R	R	R	R
Methyl bromide	—	—	C	N
Methyl butyl ketone	N	R	N	N
Methyl cellosolve	N	C	—	C
Methyl chloride	N	N	N	N
Methyl cyclopentane	N	N	—	N
Methyl ethyl ketone	N	R	N	N

*R = generally resistant; C = less resistant than R but still suitable for some conditions; N = not resistant

A dash indicates insufficient data to provide a rating.

This table is meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data are provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

Table 3.3 Chemical resistance of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		General purpose, oil resistant	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Methyl formate	N	C	N	C
Methyl isobutyl ketone	N	N	N	N
Methyl methacrylate	N	N	N	N
Methyl oleate	N	C	N	N
Methyl salicylate	—	C	—	N
Methylacrylic acid	N	C	—	C
Methylene chloride	N	N	N	N
Milk	R	R	R	R
Mineral oil	N	N	R	C
Monochlorobenzene	N	N	N	N
Monoethanolamine	C	C	N	N
Monomethyl aniline	N	—	N	N
Monomethylether	C	R	R	R
Monovinyl acetylene	C	R	R	C
Mustard gas	—	R	—	R
Naphtha	N	N	N	N
Naphthalene	N	N	N	N
Naphthenic acid	N	N	C	—
Natural gas	N	N	R	R
Neatsfoot oil	N	C	R	—
Neville acid	N	C	N	N
Nickel acetate	—	R	C	C
Nickel chloride	R	R	R	R
Nickel sulfate	C	R	R	R
Niter cake	R	R	R	R
Nitric acid (conc)	N	N	N	N

Table 3.3 Chemical resistance* of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Nitric acid (dilute)	N	C	N	R
Nitric acid—red fuming	N	N	N	N
Nitrobenzene	N	N	N	N
Nitrobenzine	—	N	—	N
Nitroethane	C	C	N	N
Nitrogen	R	R	R	R
Nitrogen tetroxide	N	N	N	N
Nitromethane	C	C	N	N
Octachlorotoluene	N	N	N	N
Octadecane	N	N	R	C
n-Octane	N	N	—	—
Octyl alcohol	C	R	C	R
Oleic acid	N	C	N	N
Oleum spirits	—	—	C	N
Olive oil	N	C	R	C
Oxalic acid	C	R	C	C
Oxygen (cold)	C	R	C	C
Oxygen (200–400°F)	N	N	N	N
Ozone	N	R	N	C
Paint thinner, Duco	N	N	—	—
Palmitic acid	C	C	R	C

*R = generally resistant; C = less resistant than R but still suitable for some conditions; N = not resistant

A dash indicates insufficient data to provide a rating.

This table is meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data are provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

Table 3.3 Chemical resistance of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Peanut oil	N	N	R	C
Perchloric acid	—	C	—	R
Perchloroethylene	N	N	N	N
Petroleum (below 250°F)	N	N	R	C
Petroleum (above 250°F)	N	N	N	N
Phenol	—	C	—	N
Phenylbenzene	N	N	N	N
Phenylethyl ether	N	N	N	N
Phenyl hydrazine	C	N	N	N
Phorone	—	C	—	—
Phosphoric acid, 20%	N	R	C	C
Phosphoric acid, 45%	N	C	N	C
Phosphorous trichloride	N	R	N	N
Pickling solution	—	N	—	—
Picric acid	C	C	C	R
Pine oil	N	N	C	N
Pinene	N	N	C	C
Piperidine	N	N	N	N
Plating solution–chrome	N	R	—	—
Plating solution–others	—	R	R	—
Polyvinyl acetate emulsion	—	R	—	C
Potassium acetate	—	R	C	C
Potassium chloride	R	R	R	R
Potassium cupro cyanide	R	R	R	R
Potassium cyanide	R	R	R	R
Potassium dichromate	C	R	R	R

Table 3.3 Chemical resistance* of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Potassium hydroxide	C	R	C	R
Potassium nitrate	R	R	R	R
Potassium sulfate	C	R	R	R
Producer gas	N	N	R	C
Propane	N	N	R	R
Propyl acetate	N	C	N	N
n-Propyl acetate	N	R	N	—
Propyl alcohol	R	R	R	R
Propyl nitrate	—	C	—	—
Propylene	N	N	N	N
Propylene oxide	—	C	—	N
Pydrauls	N	C	N	N
Pyranol	N	N	R	N
Pyridine	N	C	N	N
Pyroligneous acid	—	C	—	C
Pyrrole	N	N	N	N
Radiation	C	C	C	C
Rapeseed oil	N	R	C	C
Red oil	N	N	R	C
Sal ammoniac	R	R	R	R
Salicylic acid	C	R	R	—

*R = generally resistant; C = less resistant than R but still suitable for some conditions; N = not resistant

A dash indicates insufficient data to provide a rating.

This table is meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data are provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

Table 3.3 Chemical resistance of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Salt water	R	R	R	R
Silicate esters	N	N	C	R
Silicone greases	R	R	R	R
Silicone oils	R	R	R	R
Silver nitrate	R	R	C	R
Skydrol 500	N	R	N	N
Skydrol 7000	N	R	N	N
Soap solutions	C	R	R	R
Soda ash	R	R	R	R
Sodium acetate	N	R	C	C
Sodium bicarbonate	R	R	R	R
Sodium bisulfite	C	R	R	R
Sodium borate	R	R	R	R
Sodium chloride	R	R	R	R
Sodium cyanide	R	R	R	R
Sodium hydroxide	R	R	C	R
Sodium hypochlorite	N	C	C	C
Sodium metaphosphate	R	R	R	C
Sodium nitrate	C	R	C	R
Sodium perborate	C	R	C	C
Sodium peroxide	C	R	C	C
Sodium phosphate	R	R	R	R
Sodium silicate	R	R	R	R
Sodium sulfate	C	R	R	R
Sodium thiosulfate	C	R	C	R
Soybean oil	N	N	R	C
Stannic(ous) chloride	R	C	R	R

Table 3.3 Chemical resistance* of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Steam under 300°F	N	R	N	N
Steam over 300°F	N	C	N	N
Stearic acid	C	C	C	C
Stoddard solvent	N	N	R	N
Styrene	N	N	N	N
Sucrose solution	R	R	R	R
Sulfite liquors	C	C	C	C
Sulfur	N	R	N	R
Sulfur chloride	N	N	N	N
Sulfur dioxide	N	R	N	N
Sulfur hexafluoride	R	R	R	R
Sulfur trioxide	N	C	N	N
Sulfuric acid (dilute)	N	C	N	C
Sulfuric acid (conc)	N	C	N	N
Sulfuric acid (20% oleum)	N	N	N	N
Sulfurous acid	C	C	C	C
Tannic acid	C	R	R	R
Tar, bituminous	N	N	C	N
Tartaric acid	C	C	R	C
Terpincol	N	N	C	N
Tertiary butyl alcohol	C	C	C	C
Tertiary butyl catechol	N	C	N	C

*R = generally resistant; C = less resistant than R but still suitable for some conditions; N = not resistant

A dash indicates insufficient data to provide a rating.

This table is meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data are provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

Table 3.3 Chemical resistance of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Tertiary butyl mercaptan	N	N	N	N
Tetrabromomethane	N	N	N	—
Tetrabutyl titanate	C	R	C	R
Tetrachloroethylene	N	N	N	—
Tetraethyl lead	N	N	C	N
Tetrahydrofuran	N	C	—	—
Tetralin	N	N	N	N
Thionyl chloride	N	N		N
Titanium tetrachloride	N	N	N	N
Toluene	N	N	N	N
Toluene diisocyanate	N	R		N
Transformer oil	N	N	R	C
Transmission fluid type A	N	N	R	C
Tributoxy ethyl phosphate	C	R	N	N
Tributyl mercaptan	N	N	N	N
Tributyl phosphate	N	R	N	N
Trichloroacetic acid	C	C	C	C
Trichloroethane	N	N	N	N
Trichloroethylene	N	N	N	N
Tricresyl phosphate	N	R	N	N
Triethanol amine	C	C	N	R
Trinitrotoluene	N	N	N	C
Triocetin	N	R	C	C
Trioctyl phosphate	N	R	N	N
Trioryl phosphate	N	R	N	N
Tung oil	N	N	R	C

Table 3.3 Chemical resistance* of (PVC) gasket materials (*continued*)

	General purpose, non-oil resistant		**General purpose, oil resistant**	
ELASTOMER/ ASTM DESIGNATION	Butadiene styrene/SBR, Butadiene/BR	Ethylene propylene/EPM, EPDM	Nitrile/ NBR	Neoprene/ CR
Turbine oil	N	N	C	C
Turpentine	N	N	R	N
Unsymmetrical dimethyl hydrazine (ODMH)	—	R	C	C
Varnish	N	N	C	N
Vegetable oils	N	R	R	C
Versilube	R	R	R	R
Vinegar	C	R	C	R
Vinyl chloride	—	C	—	N
Wagner 21B fluid	R	R	N	R
Water	R	R	R	R
Whiskey, wines	R	R	R	R
White oil	N	N	R	C
White pine oil	N	N	C	N
Wood oil	N	N	R	C
Xylene	N	N	N	N
Xylidenes	N	N	N	N
Zeolites	R	R	R	R
Zinc acetate	N	R	C	C
Zinc chloride	R	R	R	R
Zinc Sulfate	C	R	R	R

*R = generally resistant; C = less resistant than R but still suitable for some conditions; N = not resistant

A dash indicates insufficient data to provide a rating.

This table is meant to aid the designer in decisions as to transporting/conveyance of undiluted chemicals. Chemical resistance data are provided as a guide only. Information is based primarily on immersion of unstressed strips in chemicals and to a lesser degree on field experience.

3.5 Permeation

Permeation is the molecular transport of chemicals through the pipe wall or gasket. Permeation may have adverse effects on the piping system, the conveyed fluid, or both. Because PVC is widely used for the transmission and distribution of potable water, it is important to understand PVC pipe's advantages and limitations regarding permeation.

The issue of permeation started to receive considerable attention in the late 1970s; since then, the topic has been thoroughly studied, evaluated, and reported on by several independent researchers, including Berens, Park, Pfau, Veenendaal, Vonk, and Gaunt. A summary of their individual findings is as follows:

- Water quality can be affected if organic soil contaminants are able to permeate water pipe walls or gasket materials.
- Organic solvents of sufficient concentration have demonstrated their ability to permeate through elastomeric gaskets, thermoplastic pipes, and asbestos cement pipes.
- PVC pipe and ductile iron pipe are impervious to gasoline and can be safely used in soils contaminated with gasoline regardless of level of contamination. There is no level of contamination at which HDPE pipe is resistant to permeation by gasoline or chlorinated solvents.
- Limited gasoline permeation takes place through the gaskets for PVC and ductile iron, as the AWWA Research Foundation (now WRF) study found.
- PVC pipe is also resistant to water solutions of benzene, toluene, and trichloroethylene (TCE) for all but the most extreme levels of environmental contamination.
- No significant permeation occurs through PVC pipes with:
  - alcohols, aliphatic hydrocarbons, and organic acids; Table 3.4 lists aliphatic hydrocarbons where permeation is not a concern;
  - benzene or alkylated benzenes if the activity of the organic chemical is less than 0.25; and
  - anilines, chlorinated hydrocarbons, ketones, and nitrobenzenes if the activity of the organic chemical is less than 0.1.

Note: An activity level of 0.25 for toluene corresponds to approximately 125 ppm in groundwater. Activity level is approximately the ratio of chemical concentration to solubility. In the vapor phase, activity is the ratio of the partial pressure (P) of the substance to its saturated vapor pressure (P_o) at the same temperature (activity = P/P_o). For liquid or solid phases, activity is most simply determined by measuring P of the vapor in equilibrium with either the liquid or solid phase.

Table 3.4 Aliphatic hydrocarbons for which permeation through PVC pipe is not a concern

• 1,2-butadiene	• ethane	• methylpropane
• 1,3-butadiene	• ethylene	• 2-methylpropene
• butane	• ethyne	• nonane
• butane-1	• heptane	• octane
• cycloheptane	• 2-heptene	• 1-octane
• cycloheptene	• hexane	• 1,3-pentadiene
• cyclohexane	• 1-hexene	• 1,4-pentadiene
• cyclohexene	• isoprene	• pentane
• cyclooctane	• methane	• pentene-1
• cyclopentane	• 2-methylpentane	• pentene-2
• 2,2-dimethylbutane	• 3-methylpentane	• propane
• 2,3-dimethylhexane	• 2-methyl-1-pentene	• propylene
• dimethylpentane	• 3-methyl-1-pentene	• 2,2,4-trimethylpentane
• 2,2-dimethylpropane	• 4-methyl-1-pentene	

The potential for PVC watermain permeation is extremely low. In those very few areas where gross organic chemical contamination does exist, no gasketed water pipeline should be installed without a site investigation taking place first.

3.6 Biological Attack

3.6.1 General Information

Biological attack is defined as degradation caused by the action of living micro- or macroorganisms. Microorganisms that attack organic materials include fungi and bacteria. Macroorganisms that can affect organic materials located underground include tree roots, insects, and rodents.

3.6.2 System Components

3.6.2.1 PVC Pipe and Fittings

During the natural cycle of growth and decay, nearly all man-made products break down. However, some plastic products are exceptions, including PVC pipe and fittings, which have proven to be immune to biological attack. Once PVC pipe has been installed in underground water and sewer systems, it is not susceptible to natural processes of deterioration.

The performance of PVC pipe in severe environments has been studied since the birth of the industry in the 1930s. These studies have found that PVC pipe does not deteriorate or break down under biological attack because PVC does not serve as a nutrient for organisms. Investigations have failed to document a single case in which buried PVC pipe products have suffered degradation or deterioration due to biological attack.

3.6.2.2 Gaskets

Elastomers used in pipe gaskets are manufactured with a variety of properties (see Chapter 2). Although natural elastomers are susceptible to biological degradation, the synthetic materials used in pipe gaskets provide high resistance to attack. For potable water systems, a material that will not support the growth of microorganisms is required.

3.6.2.3 Lubricants

Assembly of gasketed joints is facilitated by use of a lubricant recommended by the pipe manufacturer and applied in accordance with the manufacturer's instructions. Lubricants have been developed that are compatible with pipe and gasket materials and that do not support the growth of microorganisms.

3.6.3 Types of Attack

3.6.3.1 Tree Roots

Prevention of tree root intrusion is imperative in modern piping systems, and such prevention requires that: (1) pipe joints do not leak and (2) pipe does not crack. Any opening in the pipe joints may admit leakage and infiltration, providing easy access for tree roots into the pipe. Extensive experience with gasketed joint PVC pipe has found that PVC pipe is not vulnerable to root intrusion.

One research study using tree roots and gasketed pipe was performed in 1977 in Pell City, Alabama. Six PVC sewer joints (6-in. ASTM D3034, SDR 35) were assembled and then installed in a soil box. A 7-ft weeping willow tree was planted directly over the pipe joint assembly (see Fig. 3.1). A constant flow of water was provided through the pipe for the duration of the test. The results were conclusive: The test was discontinued because the tree died from lack of water.

Research conducted at the Utah State University Buried Structures Laboratory has shown that PVC pipe will not allow root intrusion even when subjected to abusive installation

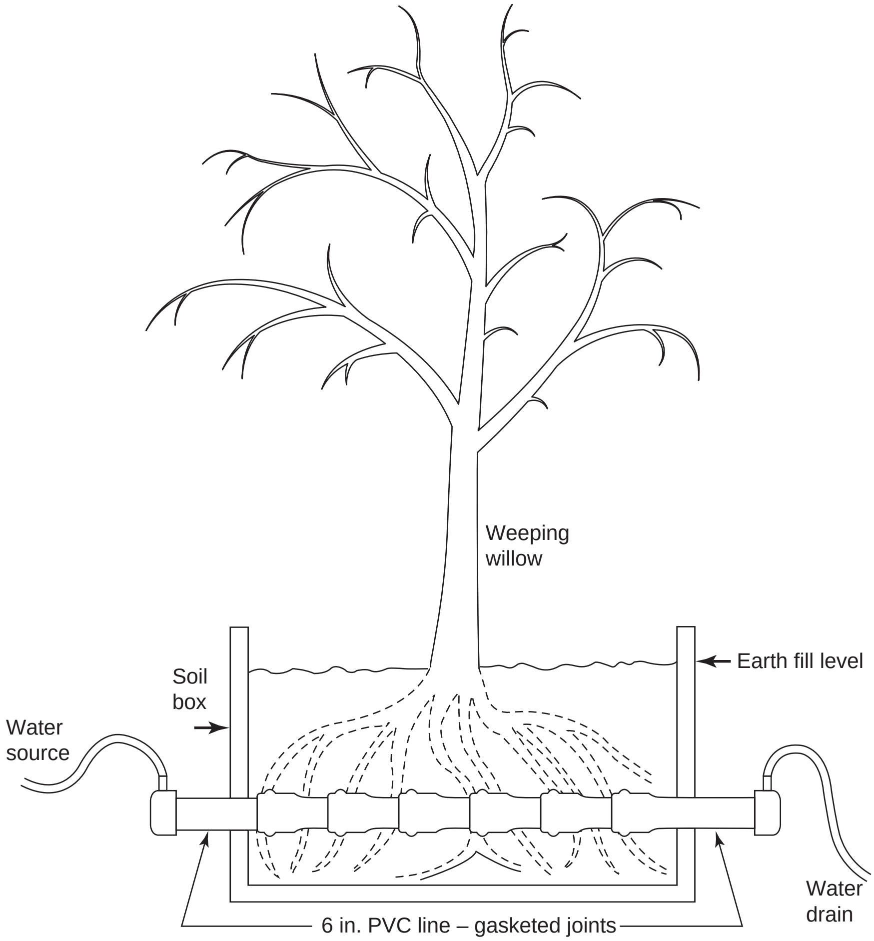

Fig. 3.1 Root resistance research.

conditions. Gasketed PVC joints remain leak-resistant, and the longitudinal flexibility allows movement without cracking, even under severe loading conditions. In this study, tests were conducted on 8-in. PVC sewer pipe (ASTM D3034, SDR 35) with integral bell-gasketed joints. Specimens were tested under loads equivalent to buried depths greater than 35 ft, and abusive conditions were created by placement of a 10-lb rock on the male spigot end adjacent to the bell joint (see Fig. 3.2). Joints were then tested with 3.5 psi air pressure, which was held for 5 min. Results summarized in Table 3.5 reveal the resistance of PVC pipe joints to leakage and associated root intrusion.

Both field experience and laboratory data clearly show that PVC sewer pipe with properly installed gasketed joints is not subject to root intrusion. The use of saws, augers, or chemicals for root removal is not necessary for PVC sewer pipe (see Uni-Bell's UNI-TR-3, Maintenance of PVC Sewer Pipe).

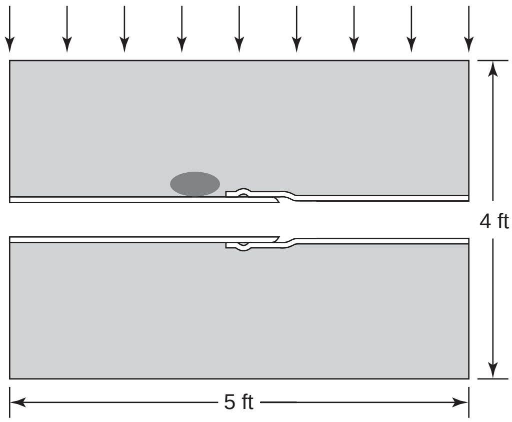

Fig. 3.2 Abusive test condition for PVC joint test in soil cell with 10-lb rock on spigot end.

Table 3.5 Results of PVC joint test

Test no.	Test description	Percent deflection when test terminated			Comments*
		Location			
		A	B	C	
1	85% soil density, no rock	33	NM	27	No leakage at 11,700 lb/ft^2 (H = 97 ft)
2	85% soil density, with rock	33	43	32	No leakage at 11,700 lb/ft^2 (H = 97 ft)
3	65% soil density, with rock	20	43	18	Joint leaked at 4,370 lb/ft^2 (H = 36 ft)
4	65% soil density, no rock	30	NM	25	No leakage at 5,840 lb/ft^2 (H = 48 ft)
		43	NM	NM	No leakage at 11,687 lb/ft^2 (H = 97 ft)

NM = no measurement.
*Leakage test conducted with 3.5 psi air pressure held for 5 min.

3.6.3.2 Insects

The insect of most concern is the termite. However, though termites have been known to attack some types of plastic, they do not attack the unplasticized PVC used in pipe. In 1955, samples of PVC were exposed to termite attack in Gulfport, Mississippi (an area regularly used for termite testing of materials). After more than four years of exposure, inspection showed no signs of termite attack on the samples. PVC pipe is not subject to attack by termites or other insects.

3.6.3.3 Rodents

NSF International (formerly the National Sanitation Foundation) conducted a series of tests designed to determine the susceptibility of PVC pipe to attack by rodents. Test sections of PVC pipe were installed in the openings of rat enclosures as barriers between rats and sources of food and water. The rats were supplied with reduced rations calculated to maintain good health but constant hunger. After one month the pipe test sections showed evidence of the rats' attempts to gnaw through to obtain food, but there was no penetration. There was also no evidence of attempted attack on the pipe where it did not interfere with access to food. PVC is not a source of nutrition, so rodents are not prone to attacking PVC pipe.

3.7 Weathering

3.7.1 UV Exposure

PVC pipe can suffer surface discoloration when exposed to ultraviolet (UV) radiation from sunlight. UV radiation affects PVC when energy from the sun causes excitation of the molecular bonds in the plastic. The resulting reaction occurs only on the exposed surface of the pipe and down to extremely shallow depths of 0.001 to 0.003 in. The effect does not continue when exposure to sunlight is terminated.

A two-year study was undertaken to quantify the effects of UV radiation on the properties of PVC pipe (see Uni-Bell's UNI-TR-5, The Effects of Ultraviolet Aging on PVC Pipe). The study found that exposure to UV radiation results in a change in the pipe's surface color and a slight reduction in impact strength. Other properties such as tensile strength (pressure rating) and modulus of elasticity (pipe stiffness) are not adversely affected.

Presence of an opaque shield between the sun and the pipe prevents UV degradation. While UV radiation will not penetrate even thin shields such as paint coatings or wrappings, burial of PVC pipe provides complete protection against UV attack.

The most common method used to protect above-ground PVC pipe from the sun is application of latex (water-based) paint. Preparation of the surface to be painted is very important: The pipe should be cleaned first to remove moisture, dirt and oil; the surface should be roughened with fine sandpaper and then wiped with a clean, dry cloth. Petroleum-based paints should not be used, since the presence of petroleum will prevent proper bonding of paint to pipe.

PVC pipe products with enhanced sunlight resistance properties—which do not need protection from UV light exposure—are also available for above-ground applications.

3.7.2 Temperature Extremes

PVC pipe durability is not adversely affected by wet/dry cycles, hot/cold cycles, or freezing temperatures. In fact, gasketed PVC pressure pipe has performed well in climates ranging from tropical to permafrost. Specific physical/mechanical property variations with temperature are addressed in Chapter 5, Section 5.3.4, and Chapter 7, Section 7.6.

Typically, pressure pipe systems are designed never to freeze while in service. However, research from Canada, where hard freezes are common, has demonstrated that buried PVC water distribution pipes are able to accommodate the stresses created by water freezing. Specifically, the National Research Council of Canada conducted a three-year evaluation on the insulating properties of different backfill materials. In addition, an investigation of rupture behavior was undertaken by the intentional freezing solid a section of PVC pipe.

The finding was that frost loadings, even with clay backfill, did not overload the pipe. The water inside the pipe was frozen solid two of the three years, yet a leak test conducted after the third winter indicated no damage to the PVC pipe. Even though water expands about 9% upon freezing, expansion was effectively restrained by the surrounding soil and the PVC pipe withstood the stresses involved.

3.8 Abrasion

Years of experience have shown that PVC pipe has exceptional resistance to abrasion; many investigations and tests in Europe and North America have been conducted to define PVC pipe's abrasion resistance. While testing methods have varied substantially, results have been consistent: The nature and resiliency of PVC pipe cause it to gradually erode over a broad area rather than develop the characteristic localized pitting and rapid failure of most other piping materials.

Tests have been conducted to investigate the resistance of PVC pipe to abrasion caused by mechanical cleaning. In tests where standard commercial cleaning and rodding equipment was used, operating in wet lines, dry lines, and lines partially filled with sand

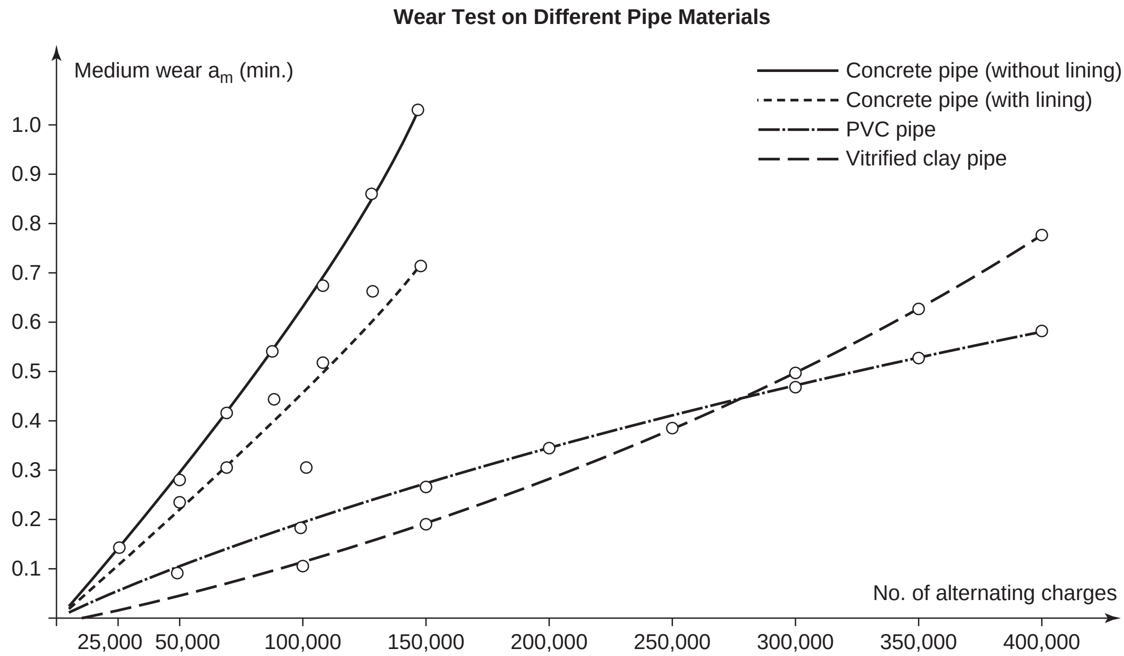

Fig. 3.3 Abrasion test results. Abrasion evaluation using river sand and gravel in unlined concrete pipe, lined concrete pipe, glazed vitrified clay pipe, and PVC pipe.

and gravel, PVC pipe showed insignificant wear for a wide assortment of conditions (see Uni-Bell's UNI-TR-3, Maintenance of PVC Sewer Pipe).

Abrasion tests were performed on several piping products by the Institute for Hydromechanic and Hydraulic Structures of the Technical University of Darmstadt, Germany. Abrasion evaluation using river sand and gravel in unlined concrete pipe, lined concrete pipe, glazed vitrified clay pipe, and PVC pipe produced the following results (see Fig. 3.3):

- Concrete (unlined): measurable wear at 150,000 cycles.
- Concrete (lined): measurable wear at 150,000 cycles (less wear than unlined concrete).
- Vitrified clay (glazed): minimal wear at 260,000 cycles (accelerated wear after glazing wore off at 260,000 cycles).
- PVC: minimal wear at 260,000 cycles (about equal to glazed vitrified clay, but less accelerated than vitrified clay).

A second German abrasion investigation included an even broader range of pipe materials. The resultant values for specific abrasion are expressed in terms of wall thickness removed and in terms of relative increase in stress under loading (refer to Table 3.6). Relative abrasion values can be used to select appropriate pipe materials and to make pipe material longevity comparisons. For example, Table 3.6 can be used to compare the values of predicted wall thickness lost due to abrasion between piping materials. Assuming a

Table 3.6 Abrasion wear of different pipe materials

Pipe material	Specific abrasion (μm)	Relative increase in stress for same abrasive effect (%)
PVC	0.754	0.6
Steel	1.72	6
Cast iron	2.09	2
Stoneware (clay)	4.31	2
Concrete	15.90	5
Asbestos cement	17.28	9

time factor of 15, the concrete pipe would lose 75% (15 × 5%) of its available wall thickness to abrasion, while a PVC pipe would lose only 9% (15 × 0.6%) of its wall thickness.

Abrasion testing has also been conducted at California State University, Sacramento, where the performance of PVC profile wall pipe versus reinforced concrete pipe was evaluated, using velocities and aggregate materials to simulate very aggressive conditions. Additionally, acidity (pH) ranges were varied to simulate common in-service conditions.

PVC pipe exhibited minimal wear at 250,000 cycles. Conversely, identical tests on reinforced concrete pipes (RCP) had to be stopped prematurely at 165,000 cycles due to wall breaches of the samples (see Figs. 3.4 and 3.5 for comparison between RCP and PVC pipes).

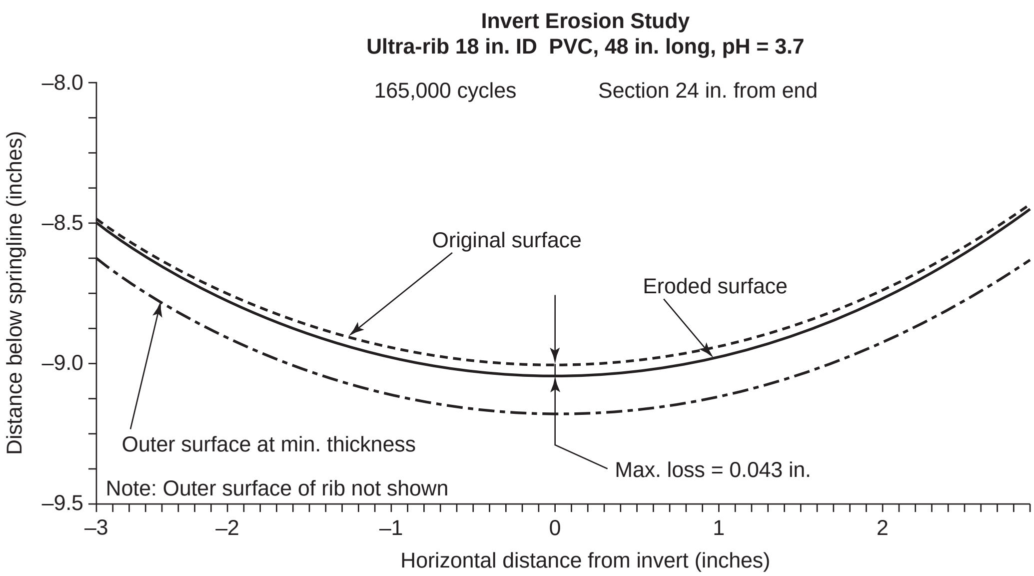

Fig. 3.4 PVC pipe invert erosion.

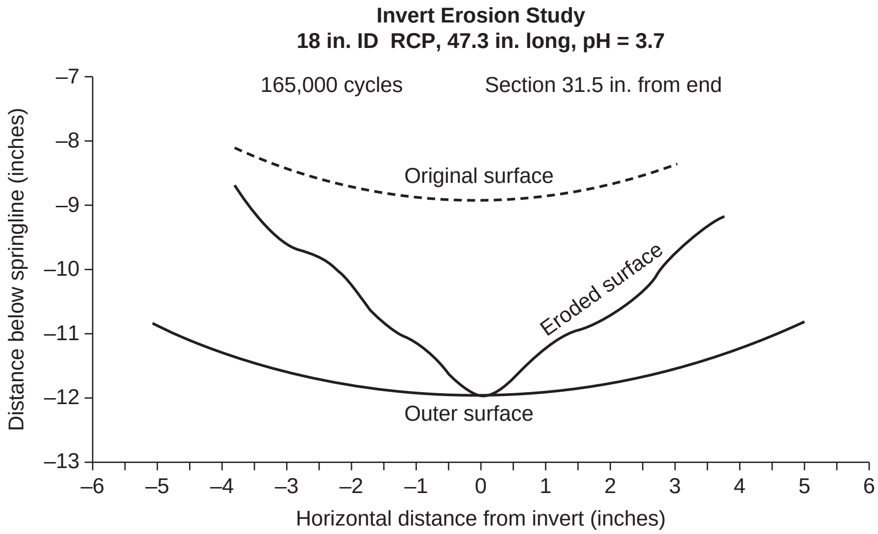

Fig. 3.5 RCP pipe invert erosion.

In this study, PVC profile pipe exhibited no measurable sensitivity or patterns of invert wear with increasing acidity of the water. Conversely, the reinforced concrete pipes (studied in parallel with the PVC pipes) were influenced by the acidity of the flowing water, with increasingly severe invert wear in response to increasing acidity.

In extremely abrasive exposures, wear must be considered. When compared with most other pipe materials, the use of PVC pipe can significantly reduce maintenance costs incurred due to abrasion and provide longer service life.

3.9 Soil Movement

While aggressive soils are often thought of in terms of the corrosion they cause, "aggressive" can also refer to their movement. Movements from expansion or contraction, frost heave, and earthquakes can turn soils into extremely aggressive environments for pipelines. If a pipeline has insufficient flexibility to allow movement, or if it has insufficient strength to resist it, the pipe will fail.

Because of their lack of flexibility, rigid pipes commonly experience beam breaks in expansive clays, shear failures due to manhole settlements, and shear and beam breaks as a result of earthquakes.

PVC pipe has longitudinal flexibility, which allows it to perform effectively while permitting relatively large movements, often making it the remedy for systems that have experienced failures due to soil movement. A survey of the San Francisco Bay Area's water distribution systems immediately following the 1989 earthquake revealed that the PVC portions of these systems performed extremely well, displaying little to no effect from the quake.

3.10 Repetitive Fatigue

Repeated stress variation is known to shorten the life of many pipe materials through fatigue. PVC pipes have been evaluated under conditions of repetitive external live loads and repetitive internal pressure surges. In Chapter 5, Design Example 5.5 includes specific information for design that accommodates frequent internal surge pressures; in Chapter 7, Section 7.8.3 discusses PVC pipe performance under dynamic external wheel loadings. PVC pipe offers exceptional capabilities of fatigue-resistance.

3.11 Sources

Acquisition of Field Data on the Performance of Buried PVC Pipes—Thermal Performance of Trench Backfills and Mechanical Performance of Buried PVC Water Mains for 1993–96. Institute for Research in Construction, National Research Council Canada, Client Report A-7022.1 (Oct. 1996).

Arnold, G.E., Experience with main breaks in four large cities. *Journal AWWA* (Aug. 1960).

ASTM D3034, Standard Specification for Type PSM Polyvinyl Chloride) (PVC) Sewer Pipe and Fittings. ASTM International, West Conshohocken, PA (2008).

ASTM F477, Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe. ASTM International (2010).

AWWA C104, Standard for Cement-Mortar Lining for Ductile-Iron Pipe and Fittings. American Water Works Association, Denver, CO (2008).

AWWA C105, Standard for Polyethylene Encasement for Ductile Iron Piping for Water and Other Liquids. American Water Works Association (2010).

AWWA C205, Standard for Cement-Mortar Protective Lining and Coating for Steel Water Pipe—4 in. (100 mm) and Larger. Applied American Water Works Association (2007).

AWWA C300, Standard for Concrete Pressure Pipe—Steel-Cylinder Type. American Water Works Association (2011).

AWWA C400, Standard for Asbestos-Cement Pressure Pipe, 4 in. through 16 in. (100 mm through 400 mm) NPS, for Water Distribution Systems. American Water Works Association (2003).

Babbitt, H.E. et al. *Water Supply Engineering*, *6th ed.* McGraw-Hill, New York (1962).

Berens, A.R., Prediction of organic chemical permeation through PVC pipe. *Journal AWWA* (Nov. 1985).

Burn, S. et al. Long term performance prediction for PVC pipes. *AWWARF* (2005).

Chemical Resistance Handbook. Plastiline Inc. Cat. PGF 0970-1, Pompano Beach, FL (1970).

Chung, S. et al. An Examination of Field Failures of Plastic Piping System Components in Potable Water Applications JANA Laboratories Inc. Aurora, Ontario, Canada. Presented ANTEC 2007, Cincinnati, OH (2007).

Colin, X. et al. Aging of polyethylene pipes transporting drinking water disinfected by chlorine dioxide. *Polymer and Engineering Science* (2009).

Corrosion Data Survey, Nonmetals Section, National Association of Corrosion Engineers (NACE). Houston, TX (1975).

Disinfection Tech Brief. A National Drinking Water Clearinghouse Fact Sheet (June 1996).

The Effects of Ultraviolet Aging on PVC Pipe—UNI-TR-5. Uni-Bell PVC Pipe Association. Dallas, TX (1997).

External Corrosion of Underground Water Distribution Piping Systems—UNI-PUB-7. Uni-Bell PVC Pipe Association. Dallas, TX (1998).

External Corrosion—Introduction to Chemistry and Control—AWWA Manual M27, 2nd ed. American Water Works Association. Denver, CO (2004).

Fumire, J., Advantages of PVC Chemical Resistance for Pressure Pipes, Presentation/PVC4 Pipes. Cologne, Germany (Oct. 2008).

Fumire, J., Resistance of PVC Pipes Against Disinfectants, *Plastic Pipes XIV*. Plastic Pipes Conferences Association. Budapest, Hungary (2008).

Gabriel, L.H., A Study of Invert Wear of Ultra-Rib PVC Profile Pipes. California State University, Sacramento, CA (1992).

Harrington, T., Performance of Pipelines during the Loma Prieta Earthquake. Unpublished presentation of 1990 AWWA California–Nevada Section Meeting, and NACE Corrosion 1990 Meeting.

Hendricks, J.C., Weathering properties of vinyl plastics. *Plastics Technology* (March 1955).

Hendricks, J.C., White, E.L. *Weathering Characteristics of Polyvinyl Chloride Type Plastics*. National Lead Company Research Laboratories, Wire and Wire Products, Brooklyn (1952).

Hertzberg, L.G., Suggested non-technical manual on corrosion for water works operators. *Journal AWWA* (June 1956).

ISO 4433-3:1997, Thermoplastics pipes—resistance to liquid chemicals—classification— Part 3: Unplasticized polyvinyl chloride (PVC-U), high-impact polyvinyl chloride (PVC-HI) and chlorinated polyvinyl chloride (PVC-C) pipes. International Organization for Standardization, Geneva, Switzerland (1997).

Janson, L.-E., *Plastic Pipe in Sanitary Engineering*. Magnestams Reklam/Christensons Grafiska AB, Lerum (1989).

Janson, L.-E., Long-Term Behaviour of Buried PVC Sewer Pipes, Plastics Pipes IX. *Plastic XIV*, Plastic Pipes Conferences Association. Edinburgh, UK (1995).

Maintenance of PVC Sewer Pipe—UNI-TR-3. Uni-Bell PVC Pipe Association. Dallas, TX (2003).

Managing Corrosion with Plastics. National Association of Corrosion Engineers. Houston, TX (1983).

Manual on Sulfides in Sewers. U.S. Environmental Protection Agency (1974).

Ong, S.A., Gaunt, J.A., Mao, F., Cheng, C-L., *Impact of Hydrocarbons on PE/PVC Pipes and Pipe Gaskets*. Water Research Foundation (formerly AWWA Research Foundation) (2008).

Park, J.K., Holsen, T.M., Bontoux, L., Jenkins, D., Selleck, R.E., *Permeation of Plastic Pipes by Organic Chemicals*. University of California Sanitary Engineering and Environmental Health Research Laboratory. Berkeley, CA (Jan. 1989).

Parker, C.D., Mechanics of corrosion of cement sewers by hydrogen sulfide. *Sewage and Industrial Wastes* (Dec. 1951).

Performance of Plastic Pipes and Pipe Gaskets in Hydrocarbon Contamination: Field Experience and Laboratory Study. Department of Civil, Construction and Environmental Engineering. Iowa State University, Ames, IA (2008).

Pfau, J.P., Sharpe, R.E., Phase III Report on Evaluation of Permeation of Organic Solvents through Polyvinyl Chloride, Asbestos Cement and Ductile Iron Water Pipes. Battelle, Columbus, OH (May 1986).

PVC Water Distribution Pipe—25 Years Later. EPCOR Water Services, Inc. Edmonton, Alberta (2007).

Rajani, B., Water Mains Break Data on Different Pipe Materials for 1992 and 1993. NRC-CNRC, Ottawa, ON (1995).

Ramirez, R., Generation and content of sulfide in filled pipes, *Sewage & Industrial Wastes* (Sept. 1954).

Reedy, D.R., Corrosion in the water works industry. *Materials Protection* (Sept. 1966).

Relative Abrasion Resistance of Ring-Tite® PVC Pipe. Johns-Manville Sales Corporation, Long Beach, CA (April 1972).

Resistance of Thermoplastic Piping Materials to Micro- and Macro-Biological Attack—PPI Technical Report, PPI-TR11. Plastics Pipe Institute, Irving, TX (2006).

Romanoff, M., External corrosion of cast iron pipe. *Journal AWWA* (Sept. 1964).

Schafer, P.L., Horner, I.S., Witzgall, R.A., Case Histories of Sulfide Corrosion. ASCE International Conference on Pipeline Design and Installation, Las Vegas, NV (1990).

Scott, C.W., *Forecasting Pipe Replacements Using Weibull Analysis*. Las Vegas Valley Water District (2009).

Spickelmire, W., *Corrosion Control Considerations for Ductile Iron Pipe—A Consultant's Perspective, 2002*. NACE International (2011).

A Study of Plastic Pipe for Potable Water Supplies. National Sanitation Foundation, Headquarters: School of Public Health, University of Michigan, Ann Arbor, MI (June 1955).

Sudrabin, L.P., Protect pipes from external corrosion. *The American City and County* (May 1956).

Swab, B.H., Effects of hydrogen sulfide on concrete structures. *Journal of Sanitary Engineering*, Division ASCE (Sept. 1961).

Test Method No. Calif. 643-C. Materials and Research Department, Division of Highways, State of California (Oct. 1972).

Test to Determine Effect of an Undersized (Smaller Diameter than Inside Diameter of Pipe and Fittings) Electrical Sewer Pipe Auger on Schedule 40 PVC-1 Drain, Waste, and Vent Pipe and Fittings. Report from Research Laboratory, Carlon. Aurora, OH (May 1963).

Thermoplastic Piping for the Transport of Chemicals—PPI Technical Report, PPI—TR19. Plastics Pipe Institute, New York (2007).

Tiedeman, W.D., *A Study of Plastic Pipe for Potable Water Supplies*. National Sanitation Foundation, Ann Arbor, MI (June 1955).

Tipps, C.W., Underground corrosion. *Materials Protection* (Sept. 1966).

Tobin, W.W., Stabilization of Rigid Polyvinyl Chloride Against Ultraviolet Radiation. Presented at Society of Plastic Engineers 21st Annual Technical Conference, Boston (March 1965).

Transport fester Stoffe durch PVC–hart–Rohre (Transport of Solid Substances through Hard PVC Pipes). Code: 237-4032-1 (German).

United States Environmental Protection Agency, Hydrogen Sulfide Corrosion in Wastewater Collection and Treatment Systems. Office of Water (WH-595), Washington, DC (May, 1991).

Vonk, M.W., Permeation of organic soil contaminants through polyethylene, polyvinyl chloride, asbestos cement and concrete water pipes. In: *Some Phenomena Affecting Water Quality During Distribution: Permeation, Lead Release, Regrowth of Bacteria*. KIWA Ltd., Neuwegen, The Netherlands (Nov. 1985).

Wagner, E.F., Loose plastic film wrap as cast iron protection. *Journal AWWA* (March 1964).

Wear Data of Different Pipe Materials at Sewer Pipelines. The Institute for Hydromechanic and Hydraulic Structures, Technical University of Darmstadt, Darmstadt, West Germany (May 1973).

Weisfeld, L.B., Thacker, G.A., Nass, L.I., Photodegradation of rigid polyvinyl chloride. *SPE Journal* Vol. 21, No. 7 (July 1965).

Wolter, F., Effect of Outdoor Weathering on the Performance of Some Selected Plastic Piping Materials. Presented by Battelle at the American Gas Association Fifth Plastic Pipe Symposium, Houston, TX (Nov. 1974).

Yearbook and Directory. The Los Angeles Rubber Group, Inc., Los Angeles, CA (1970).