Engineering Handbook

SYGEF® PVDF Pressure Piping System

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GEORG FISCHER
PIPING SYSTEMS

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Material Characteristics

General Information

Polyvinylidene Fluoride (PVDF) is a semi-crystalline thermoplastic having outstanding mechanical, physical and chemical properties. These result from the chemical structure of PVDF. Polyvinylidene Fluoride belongs to the class of fluorinated polymers, whose best-known representative is polytetrafluoroethylene (PTFE). PTFE is characterized by a superb heat resistance and the best chemical resistance of all polymers; a great disadvantage is that it is not melt processable - e.g. into fittings. PVDF, on the other hand, combines various advantages of PTFE with good workability into structural parts. The fluorine content in PVDF amounts to 59% by weight.

PVDF from GF is characterized by a very good mechanical behavior and high temperature resistance. Because of the exceptionally wide pressure/temperature range in which PVDF can be used, it has opened, in connection with the specific characteristics of this material, completely new areas of application in plastic piping fabrication. These include applications in the semi-conductor, chemical and pharmaceutical industry, electroplating, paper and cellulose processing, the automotive industry and water treatment. Pipes, fittings and valves of PVDF are uncolored and opaque (milky, translucent).

By avoiding the addition of any additives, the outstanding characteristics of the material remain to the fullest extent, especially concerning the chemical resistance and physiological harmlessness.

Advantages

- outstanding mechanical properties, even at high temperatures
- excellent chemical resistance
- no electrochemical corrosion
- long service life, even under intensely corrosive conditions
- outstanding resistance against Sunlight and Y-radiation
- very pure material without additives, stabilizers or plasticizers
- inhospitable to microbial growth
- physiologically harmless
- secure jointing by high-quality welding technology
- produced with smooth inner surfaces
- very low heat conductivity
- excellent flame retardant properties

Mechanical Properties

PVDF has a high tensile strength and stiffness. The impact strength is still good at temperatures around 32°F (0°C). PVDF's advantages are particularly prevalent at higher temperatures. This is due to the high fluorine content which causes strong interactions between the PVDF chains. This, in turn, displaces the softening and the loss of properties to higher temperatures. This also has an effect on the long-term creep strength.

PVDF has the highest long-term creep strength of all the polymers used for GF piping systems. The long-term behavior for internal pressure resistance is provided by the hydrostatic strength curve based on the DVS 2205-1 Guidelines, Supplement 4 (see also the Pressure/Temperature section). The application limits for pipes and fittings, as shown in the pressure and temperature diagram, can be determined from these curves.

Chemical, Weathering, and Abrasion Resistance

PVDF is resistant to most inorganic solvents and additionally to aliphatic and aromatic hydrocarbons, organic acids, alcohol and halogenated solvents. PVDF is also not attacked by dry and moist halogens with the exception of fluorine. PVDF is not resistant against strong basic amines, alkalis, and alkaline metals. Strong polar solvents, such as ketones and esters and organic acids can cause PVDF to swell somewhat.

For detailed information, please refer to the detailed list of chemical resistance from GF or contact your GF subsidiary.

Outstanding resistance against UV light as well as gamma radiation permits, among other applications, the use of PVDF piping outdoors. No loss of properties occurs. Abrasion resistance is considerable and approximately comparable to that of polyamide.

Thermal Properties

PVDF shows its outstanding properties in a temperature range from -4ºF (-20°C) to 284ºF (140ºC). This allows using the material in a wide range of applications. Especially at high temperatures, PVDF provides maximum security. Its high crystalline melting point at around 343ºF (173°C) speaks for itself.

Please consult the pressure-temperature diagrams for your operational temperature. For temperatures below 32ºF (0°C), the media must be prevented from freezing to avoid damaging the piping (as for other piping materials).

With a thermal coefficient of linear expansion of 0.78×10^{-4} in/inºF, PVDF lies clearly above that of metals. Because of this, its thermal expansion must be taken into account during the planning of the piping system. As for all polymers, PVDF is a good thermal insulator because its heat conductivity of 1.3 BTU-in/ft^2/hr/ºF is very low. (For comparison, the value for steel is 1733 BTU-in/ft^2/hr/ºF).

Flammability and Fire Testing

Combustion Behavior

PVDF displays an exceptionally good combustion behavior without the addition of fire protection additives. Material decomposition begins at 716°F (380°C). The oxygen index amounts to 44%. (Materials that burn with less than 21% of oxygen in the air are considered to be flammable).

PVDF thus also falls in the best flammability class V0 according to UL94, and in the building materials class B1 (difficult to ignite) according to DIN 4102-1.

SYGEF® PVDF products show such excellent fire safety behavior that they are accepted and listed by Factory Mutual for use in clean rooms (FM 4910).

Comparative oxygen indices

Material	% Oxygen
PMMA	17.3
PE	17.4
PP	17.4
PIB	17.7
PS	18.1
PC	27.0
PA 6.6	29.0
ETFE	30.0
SYGEF®	43.7
PVC	45
PTFE	95

Installation within Designated Return Air Plenums

Current regulations and standards for testing materials for installations within designated return air plenums under IMC (International Mechanical Code), UMC (Uniform Mechanical Code/IAPMO, NFPA 90A,etc. are being reviewed with regards to non-ferrous process water piping systems. These reviews may lead to changes in required testing procedures and certifications for product conformance. For proposed installations of SYGEF® PVDF Piping systems within designated return air plenums, please contact your local GF Area Sales Manager prior to preparing project specifications.

Fire Testing

Since the combustion of PVDF produces hydrogen fluoride, which forms a corrosive acid in connection with water, immediate cleaning of areas susceptible to corrosion with water containing detergent is necessary after a fire. Additional combustion products are carbon monoxide and carbon dioxide. Concerning the choice of fire-fighting agents, sand or powder-type extinguishing agents are recommended because the use of water may result in the development of corrosive acids. Test method according to ASTM D635 The end of a test specimen is held horizontally, for 30 seconds, in the flame of a Bunsen burner, the narrow side of the specimen being inclined at an angle of 45°.

PVDF stops burning immediately if the flame is removed. By way of comparison, unplasticised PVC also stops burning immediately, while self-extinguishing polyester continues to burn for 2 seconds after the source of ignition has been removed.

The HOOKER HLT 15 flame test This method of test is much more stringent than the ASTM D635 test. The test permits the classification of non-flammable products into various categories.

A test specimen prepared according to ASTM D635 is clamped vertically and is then periodically exposed to the Bunsen flame, using the following rhythm:

The test specimen must have stopped burning at any rate before the flame is applied again.

Duration	Operation
5 seconds	1st Contact with Flame
10 seconds	Flame Removed
7 seconds	2st Contact with Flame
14 seconds	Flame Removed
10 seconds	3st Contact with Flame
20 seconds	Flame Removed
15 seconds	4st Contact with Flame
30 seconds	Flame Removed
25 seconds	5st Contact with Flame
50 seconds	Flame Removed

SYGEF® will withstand four contact cycles with the flame. After the fifth contact it melts, but without burning.

ISO R 181 test according to SCHRAMM

A flat test specimen in horizontal position is pressed for 3 min. against a rod heated to 1742°F (950°C). The loss in weight p in mg is then determined, together with the longitudinal shrinkage L in cm and assessed according to the following equation: Lg = 100,000 pL in degrees SCHRAMM

For SYGEF®, the result is 2.2 degrees SCHRAMM. By way of comparison, unplasticised PVC shows 2.2 degrees SCHRAMM also, and self-extinguishing polyester 2.5 degrees SCHRAMM

Electrical Properties

PVDF is a good electrical insulator. Because of the possible electrostatic charges, caution is recommended when using PVDF in applications where combustion or explosion dangers exist. The specific volume resistance is >10^{14} Ωcm; the specific surface resistance is 10^{14} Ω.

Physiological Properties

PVDF is physiologically non-toxic as long as it is used below the maximum temperature of 302°F (150°C). During welding, good ventilation is required or alternately the released gases must be extracted.

PVDF can be used in the USA in accordance with the relevant regulations of the Food and Drug Administration (FDA) for food packaging and items that come into contact with food. The Federal Health Ministry of Germany generally recommends that plastic items containing fluorine be thoroughly rinsed or boiled before their first use - a common procedure usual for other materials too.

Extractables

PVDF is a pure resin. Unlike other plastics, SYGEF® PVDF does not contain additives, stabilizers, antioxidants or extrusion/injection molding aides. It is considered to be chemically inert and is not water soluble. SYGEF® Plus HP Grade PVDF pipes and fittings are comprised of only PVDF while SYGEF® Plus HP Grade Valves also contain PTFE diaphragms. Testing shows that PVDF is not detectable in water.

SYGEF® Plus HP Grade PVDF yields no polymeric extractables at any temperature. At elevated temperatures, fluoride is a detectable ionic extractable in trace amounts yielding water quality well within USP specifications for production of DI, USP and WFI. Testing with hot deionized water shows that trace elements are detectable at extremely low levels as surface contaminants. They virtually disappear after the system is adequately flushed. Dynamic testing under flowing conditions also indicated that the amount of extractables challenge the detection limits of modern analytical test equipment.

Additionally, SYGEF® Plus HP Grade PVDF piping system components comply with the recommendations of SEMI F57 Guidelines for extractable levels of metallic and ionic contaminants as well as TOC for polymer components. These levels are far below those seen with traditional metal piping systems used widely in the pharmaceutical industry.

Discoloration Phenomena

PVDF exhibits a more intense degree of color change due to heat history and chemical effects when compared to other thermoplastics. Because PVDF is absent of additives, changes in coloration are exhibited far more readily than otherwise expected.

Coloration changes can vary from beige to dark brown. It is important to recognize that even a major discoloration (brown) does not always relate to a degradation of the polymer. Such discoloration is common for PVDF materials operating in hot ultrapure water systems at 158°F (70°C) to 176°F (80°C) and is the result of minor double bonding of carbon along the PVDF linear molecule chain.

According to a 1993 report by a PVDF raw material supplier, the theoretical effects of such discoloration of PVDF are outlined as follows:

- PVDF becomes completely black when only (1) in (1000) of PVDF monomer (-CH2-CF2-) transform to a (-CH=CF-) molecule
- In a 3.2ft length of 2in (63mm) pipe there are about $2ft^2$. of surface area
- When the discoloration affects .03937in of the surface (entire pipe appears black), this volume is $11in^3$.
- PVDF has a density of ~ $0.06lb/in^3$, therefore, $11in^3$. Weights ~ 0.7lb.
- Since 59% of the (-CH2-CF2-) monomer is F2, the loss of 1 atom of F per 1000 results in $2.0x10^{-4}$lbs F being removed from the 3.2ft of pipe material; (0.7lb x 59%/2 x 1/1000) = $2.0x10^{-4}$lbs
- There are 6.02 $x10^{23}$ atoms per 0.04lb F; hence, $2.0x10^{-4}$lbs is equivalent to 2.98 x 10^{21} atoms
- If a 2in (63mm) pipe has a velocity of 5ft/sec., then the flow is approximately 61 gallons/min.
- Because brown discoloration occurs within 2 weeks time in a hot UPW system, the amount of H^2O passing through this 3.2ft of pipe is about $0.17x10^6ft^3$.
- Therefore, this 0.094g is diluted to levels challenging detection capabilities even when the PVDF appears black $2.0x10^{-4}lbs/0.17x10^6ft^3$ = ~ 19ppt
- If a conservative factor of 1000 is used to demonstrate the difference between the first signs of discoloration (brown) and the 1 per 1000 rule (black) the value is easily < 0.019ppt Fire Rated Construction

Manufacturing

Complete System of Pipe, Fittings and Valves

The production hall for SYGEF® Plus HP (PVDF) pipes, fittings and valves shall be maintained at Class 10,000 Cleanroom (ISO Class 7) or better as defined by the current ISO Standard 14644-1. Specific class levels are assigned for each level of production as described later in this section.

SYGEF® (PVDF) pipe shall be a Standard Dimensions Ratio (SDR) series which defines the outer pipe diameter, wall thickness and tolerances. GF produces pipe and fittings rated for 232psi (16bar) from 3/8" (16mm) to 8" (225mm) and 150psi (10 bar) from 3" (90mm) to 18" (450mm) when measured at 68°F (20°C).

Flanged connections have ANSI 150# bolt pattern. All mechanical connections for sample ports, instrumentation or venting have either sanitary or approved ANSI threaded NPT connections.

All SYGEF® Plus HP (PVDF) valves have a minimum pressure rating of 150psi (10bar) at 68°F (23°C). High purity PVDF valves in sizes through 2" (63mm) are Type 514/515 Diaphragm Valves as manufactured by GF. Additionally, Type 519 Zero-Static Lateral Valves are available up to 4" (110mm) along the run. All diaphragm valves are weir style with PTFE diaphragm seals backed with EPDM or FPM.

Compliance with Microelectronics Standards

Compliance with industry standards is very important to Georg Fischer. This is especially the case in the field of high purity where SYGEF® Plus HP Grade (PVDF) piping system components are required to convey ultrapure water (UPW) and high purity chemicals with qualities as characterized within SEMI documentation. Disregard for this requirement would impart serious yield losses to the high tech end-users of piping systems.

For example, SEMI F63 defines the UPW quality used in today's sub-100 nanometer semiconductor factories. SEMI F57 outlines the critical characteristics and performance criteria of polymer raw materials and components. SEMI F40 gives the necessary steps for testing these raw materials and components.

To insure that manufacturing conditions and final product meet or exceed the requirements of SEMI F57 guidelines for extractable levels of metallic, ionic and organic (TOC) contaminants standardized testing regimes have been adopted within Georg Fischer's high purity facility. This strict compliance to SEMI F57 demands routine sampling of production pipes, fittings and valves, which are submitted to certified laboratories for testing using SEMI F40 protocol. Databases with Cpk (process capability) indices are maintained and monitored for early warning indications of potential problems in either raw material purity or production induced changes.

The leached levels seen in SYGEF® Plus HP (PVDF) continue to provide demanding customers with satisfactory results. At the same time, they are far below those found coming from traditional metal piping systems, which are widely used in the pharmaceutical industry.

Compliance with Life Science Standards

SYGEF® Plus HP (PVDF) Piping Systems have been installed for use in Deionized (DI) Water, USP Water, and WFI systems and are well suited to these applications. This material can be sanitized using hot water, steam, ozonation or chemicals and does not require passivation for the life of the system. It can also be steam sterilized. Additionally, since SYGEF® Plus HP (PVDF) piping components are produced and packaged in a high purity environment, no Clean In Place (CIP) procedures are required at startup, provided that installation occurs in a controlled environment.

SYGEF® Plus HP (PVDF) meets the requirements of ASME BPE (Bioprocessing Equipment) Standard, Section PM and Section SF.

Recent changes in the USP XXIII call for water to pass the Total Organic Carbon (TOC) test with limits of ≤ 500 ppb. Historically, the users of PVDF systems have focused on the much more rigorous TOC requirements of the microelectronics industry. These systems typically pass using on-line monitoring equipment at limits of ≤ 5 ppb, 100 times more stringent than the current USP XXIII requirement. Of significant importance, these results have been achieved with virtually no unscheduled down time.

SYGEF® Plus HP (PVDF) has measurably smoother surfaces than those found in common grades of stainless steel used in pharmaceutical systems. Piping system components are made from a pure fluoropolymer resin, containing no metals such as iron, copper or nickel. This inert pipe cannot experience rouging or pitting corrosion. Additionally the BCF welding process provides smooth weld surfaces, far superior to the results produced by welding on stainless steel. In stainless steel systems, microscopic pitting from corrosion of the pipe surface, as well as welding beads create rough surfaces which can harbor microorganisms. This smoother surface, combined with the smoother BCF weld result, presents fewer opportunities on the piping system component surface for bacteria to adhere and proliferate. Thus, it requires less frequent sanitization and less production down time.

Raw Materials

SYGEF® Plus HP (PVDF) pipe, fittings and valves shall be manufactured from natural, unpigmented, virgin polyvinylidene fluoride (PVDF) homopolymer conforming to the standards of ASTM D3222. All raw material utilized for SYGEF® Plus HP (PVDF) production shall be specially controlled regarding procurement, shipment, handling and storage prior to production to minimize contact with extraneous contamination.

PVDF raw materials shall be handled in a clean room environment to prevent contamination. The raw material shall be gravity fed into the processing equipment. Pneumatic conveyance of the raw material is prohibited.

PVDF raw material shall meet the testing requirements for impurities per SEMI F57.

Manufacturing (Pipe)

Environment

SYGEF® Plus HP (PVDF) pipe shall be extruded in a dedicated high purity PVDF production area which is located in a Class 1,000 Cleanroom (ISO Class 6) or better environment. All pipes shall be extruded on dedicated production equipment used exclusively for the production of high purity PVDF. Pipe dimensions and tolerances shall be continually monitored with QC sampling at designated time intervals compliant with Good Manufacturing Practices.

Stress Relieving:

Extrusion stresses shall be relieved by use of a continuous in-line annealing oven. Stress relief shall be measured and relate to a maximum 0.4% dimensional change when tested according to ISO 10931-2

Pipe Identification

SYGEF® Plus HP (PVDF) pipe shall be identified on the pipe outer surface (on top) with the production lot, pipe diameter and wall thickness. Pipe identification shall be accomplished by use of heat embossed lettering and without the use of any ink on the pipe surface. After packaging, each pipe length shall have a label adhered to the outside of the outer polyethylene bag. The label shall denote production lot, pipe diameter, wall thickness and surface quality.

Surface Finish

SYGEF® Plus HP (PVDF) pipe shall have samples taken which are measured for mean roughness of the interior pipe surface.

Using ISO 4288, SYGEF® Plus HP (PVDF) pipe, shall have profilometer mean roughness values compliant with SEMI F57 or better.

Pipe interior shall also be visually inspected for defects on a lighted table prior to fitting with protective polyethylene end caps and double bagged in heat sealed polyethylene liners immediately after production within the cleanroom.

Pipe Dimensional tolerances

Pipe shall be in accordance to the following values:

Size	Tolerance	Ovality	Wall	Tolerance
1/2" (20mm)	+0.3, -0.0	0.3	1.9	+0.4, -0.0
3/4" (25mm)	+0.3, -0.0	0.4	1.9	+0.4, -0.0
1" (32mm)	+0.3, -0.0	0.5	2.4	+0.5, -0.0
1 1/4" (40mm)	+0.3, -0.0	0.5	2.4	+0.5, -0.0
1 1/2" (50mm)	+0.3, -0.0	0.6	3.0	+0.6, -0.0
2" (63mm)	+0.4, -0.0	0.8	3.0	+0.6, -0.0
2 1/2" (75mm)	+0.4, -0.0	0.9	3.6	+0.6, -0.0
3" (90mm)	+0.4, -0.0	1.1	4.3	+0.7, -0.0
4" (110mm)	+0.5, -0.0	1.3	5.3	+0.8, -0.0
6" (160mm)	+1.0, -0.0	2.0	4.9	+0.8, -0.0
8" (200mm)	+1.2, -0.0	2.5	6.3	+0.9, -0.0
8" (225mm)	+1.4, -0.0	2.7	6.9	+0.9, -0.0
10" (250mm)	+1.4, -0.0	3.1	7.7	+1.1, -0.0
12" (315mm)	+1.6, -0.0	3.9	9.7	+1.3, -0.0
14" (355mm)	+1.9, -0.0	4.4	10.8	+1.4, -0.0
16" (400mm)	+2.1, -0.0	5.0	12.1	+1.6, -0.0
18" (450mm)	+2.4, -0.0	5.6	13.6	+1.8, -0.0

Manufacturing (Fittings/Valves)

Environment

All high purity PVDF fittings and valves shall be manufactured on dedicated equipment in clean production cells that are Class 100 (ISO Class 5) or better. Any machined valve components shall be performed with no coolant other than filtered air.

Cleaning

Fittings and valves (diaphragm) shall be washed in a Class 100 Cleanroom (ISO Class 5), using DI water with nonionic, phosphate free surfactant solution. After cleaning, the components shall be rinsed with hot (176°F/80°C) UPW water, flushed with ambient UPW water, both meeting SEMI F63-00-0701 requirements, and heat dried with HEPA filtered air or filtered nitrogen.

Identification

All high purity PVDF fittings and valves shall be molded with permanent identification to allow tractability to production lot and raw material batch.

In addition, all high purity PVDF fitting and valve labels shall have an identification code or numbering scheme on the packaging that permits traceability back to the lot and batch cleaning of fittings or valves.

Packaging

After cleaning, fittings and valves shall be immediately and individually heat sealed in PA6/PE double bags while in the cleanroom. Valves shall be assembled in a Class 100 (ISO Class 5) environment. No external markings or labeling shall be permitted except on the outer bag. The production label shall denote production lot, dimension and logistical information.

Manufacturing (Fabricated Products)

Production of PVDF fabricated items are to be done under a minimum Class 10,000 cleanroom as defined in the current Federal Standard. Machine components made from semi-finished PVDF block and rod used in this fabrication of parts or sub-assemblies shall be inspected, cleaned and packaged similar to fittings and valves. Final inspection is made prior to packaging by 100% visual inspection of every weld. Pressure test for welded assemblies as required. Surface finish for any machined component shall be: Ra = 0.62µ or better.

Tracebility of Machined Components

Welding of sub-components shall only be done by manufacturers certified technicians. All factory welds shall be labeled using the manufacturers fusion machine printouts from actual welds. All finished parts and assemblies shall be permanently marked with a traceable number which links incoming material, production dates, machines used and welding personnel.

Delivery, Storage and Handling

Any material that becomes damaged and/or contaminated in transit handling or storage shall not be used. It must be rejected by the quality control representative and returned to the manufacturer/distributor.

All material and equipment shall be handled and stored in an indoor location throughout the progress of the job in such a manner as to prevent damage and/or contamination. Room shall be maintained dry and dust free. Room shall be kept at a temperature between 60°F (15°C) and 85°F (30°C).

Piping, fittings, and valves shall be stored in their original factory sealed poly bags. Use nylon or polypropylene rope or soft strand for slings and tie-downs used to let, load, or transport pipe bundles. Do not stack pipe higher than 2 feet.

All fabricated material shall be used within 48 hours of being removed from the storage site. All high-purity PVDF piping system components shall be inspected and approved by fabricator and installer upon arrival into the fabrication clean room and before spool fabrication begins.

Fabricated spool pieces shall be supported and padded to prevent damage during transport.

All pipe fitting ends of fabricated spool pieces shall be double bagged and sealed. Bags shall be secured with cap or cleanroom tape a minimum 6 inches away from pipe end. Cleanroom tape directly over pipe or fitting end is not acceptable. Dae nihilit etus, eat volorit iatianis vera dolupienet que verum am volupti bla duntotatur, cum accuptis dunt.

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General Properties - SYGEF® PVDF (Polyvinylidene Fluoride)

Material Data

The following table lists typical physical properties of PVDF (Polyvinylidene Flouride) thermoplastic materials. Variations may exist depending on specific compounds and product.

Mechanical

Properties	Unit	SYGEF® Plus HP/Standard PVDF	ASTM Test
Density	lb/in^3	0.0643	ASTM D792
Tensile Strength @ 73°F (Yield)	PSI	≥ 7,250	ASTM D638
Tensile Strength @ 73°F (Break)	PSI	≥ 6,500	ASTM D638
Modules of Elasticity Tensile @ 73°F	PSI	≥ 246,560	ASTM D638
Compressive Strength @ 73°F	PSI	12,500	ASTM D695
Flexural Modulus @ 73°F	PSI	267,500	ASTM D790
Izod Impact @ 73°F	Ft-Lbs/In of Notch	≥ 3.8	ASTM D256
Relative Hardness @ 73°F	Durometer "D"	78	ASTM D2240

Thermodynamics

Properties	Unit	SYGEF®	ASTM Test
Melt Index	gm/10min	1.10	ASTM D1238
Melting Point	°F	≥ 336	ASTM D789
Coefficient of Thermal Linear Expansion per °F	in/in/°F	0.67...1.00 (x 10^{-4})	ASTM D696
Thermal Conductivity	$BTU\text{-}in/ft^2/hr/°F$	75	ASTM D177
Specific Heat	CAL/g/°C	0.32	DSC
Maximum Operating Temperature	°F	284	
Heat Distortion Temperature @ 264 PSI	°F	≥ 220	ASTM D648

Other

Properties	Unit	SYGEF®	ASTM Test
Water Absorption	%	≤ 0.04	ASTM D570
Limited Oxygen Index (LOI)	%	≥ 43	
Industry Standard Color		Opaque	RAL 9005
Food and Drug Association (FDA)		YES	CFR21.177.1520
United States Pharmacopeia (USP)		YES	USP 25 Class VI
SEMI		YES	F57
Factory Mutual		YES	FM4910

Note: This data is based on information compiled from multiple sources.

SYGEF® Plus HP PVDF Specification - IR/BCF

PART 2 - PRODUCTS – MATERIALS

2.01 PURE WATER PIPE AND FITTINGS

A. Polyvinylidene Fluoride pipe shall be manufactured from a virgin resin material, unpigmented and translucent. Dimensions for all sizes shall be in accordance to ISO 10931. Pipe sizes 1/2" (20mm) through 4" (110mm) shall be manufactured to have a pressure rating of 232 psi (16 bar) when measured at 68°F (20°C). Pipe sizes 3in (90mm) through 18" (450mm) shall be manufactured to have a pressure rating of 150 psi (10 bar) when measured at 68°F (20°C). Pipe shall be manufactured and catalogued for BCF® Bead and Crevice Free) or IR® (Infrared) methods. Pipe internal surface finish: for ≤ 8"(225mm) shall have an Ra ≤ 9.0µin (0.2µm) / for > 8"(225mm) shall have an Ra ≤ 12µin (0.3µm) / for 12"(315mm) shall have an Ra ≤ 16.0µin (0.4µm).

B. Polyvinylidene Fluoride fittings shall be manufactured from a virgin resin material, unpigmented and translucent. Fittings 1/2" (20mm) through 4" (110mm) shall be manufactured to have a pressure rating of 232 psi (16 bar) when measured at 68° F (20° C). Fitting sizes 3" (90mm) through 18" (450mm) shall be manufactured to have a pressure rating of 150 psi (10 bar) when measured at 68°F (20°C). Fittings shall be manufactured and catalogued for BCF® (Bead and Crevice Free) or IR® (Infrared) methods. Fitting internal surface finish: for ≤ 8"(225mm) shall have an Ra ≤ 9.0µin (0.2µm) / for > 8"(225mm) shall have an Ra ≤ 12.0µin (0.3µm) / for 12"(315mm) shall have an Ra ≤ 16.0µin (0.4µm).

C. Pipe and fittings shall have a temperature rating of -4°F (-20°C) to 284°F (140°C).

D. All components of the pipe and fitting system shall conform to FDA CFR 21 177.1520 (certificate of conformance to be included with shop drawing submittal), USP 25 Class VI (certificate of conformance to be provided with shop drawing submittal) and ASME-BPE. All pipe and fittings shall be marked with brand name, product description, code number, material, and dimension and pressure rating information. Fittings shall be embossed with a permanent identification during the production process to ensure full traceability.

E. Pipe and fittings shall be produced under ISO 14644-1 Class 7 (U.S. Fed. Standard 2.09 E Class 10'000) conditions. Subsequent assembly, quality inspection and cleaning is to be carried out using 18MΩ pure water under clean room ISO 14644-1 Class 5-6 (U.S. Fed. Standard 2.09E class 100-1000) conditions. Pipes will be capped and each component (pipe and fittings) will be double bagged in a specified inner bag and an outer bag under clean room ISO 14644-1 class 6 (U.S. Fed. Standard 2.09E Class 1000) conditions.

F. Shall be SYGEF® Plus PVDF Piping Systems as manufactured by GF Piping Systems LLC, Tustin CA.

2.02 VALVES

A. Diaphragm Valves: Diaphragm valves shall be constructed of polyvinylidene fluoride with EPDM or PTFE Seal configurations, manufactured for installation in SYGEF® Plus Piping system, Type 514, 515, 517 and 519 (Zero Static) as manufactured by GF Piping Systems LLC. Diaphragm valves shall be rated for 240 psi (16.5 bar) when measured at 68°F (20°C). Pneumatic/Electrical valve actuators, if required, shall be supplied by GF Piping Systems LLC to ensure proper system operation.

2.03 RECIRCULATING LABORATORY FAUCET

A. Recirculating Laboratory Faucet: Shall be constructed of polyvinylidene fluoride and designed to provide a constant fluid flow to the point of use to eliminate dead legs. Faucet shall be Type 530 "Aqua Tap" as manufactured by GF Piping Systems LLC, Tustin CA.

   a. Faucet to be manufactured with needle type flow control for precise metering.

b. Faucet to be manufactured for deck or wall mounting options.

c. Recirculating laboratory faucet shall be installed in conjunction with an inline flow diverter (IFD) manufactured of SYGEF® PVDF or PROGEF® Natural PP by GF Piping Systems LLC. The inline flow diverter shall be designed to provide high flow from the distribution main through the faucet for constant water movement. An orifice installed within the inline flow diverter is used to create a differential pressure imbalance which forces water through the faucet with minimal pressure loss. The inline flow diverter(s) shall be installed in the distribution main where shown on the drawings and may serve up to three faucets. The diverters shall be manufactured and catalogued for BCF® (Bead and Crevice Free), IR® (Infrared) or sanitary clamp joining methods.

d. Faucet shall have a pressure rating of 92 psi (6 bar).

e. Recirculating laboratory faucet(s) shall be connected to the inline flow diverter using smooth bore 5/8" PFA or PE tubing for design flexibility and simplified piping installations. Tubing shall be connected to faucet(s) and inline flow diverter connection points using easy flare style connection method. Installer shall use GF Piping Systems LLC isolation ball valves installed inline (tubing) or optional emergency shut-off clamps, to facilitate segregation of faucets from the pure water system if required for maintenance or other purposes. Only catalogued AquaTap adaptors, accessories and tools shall be used by the installer.

PART 3 - EXECUTION

3.1 HANDLING

A. Material shall be stored in original packaging and protected from environmental damage until installation. Pipe shall be supported sufficiently to prevent sagging. Care shall be taken not to gouge or otherwise notch the pipe in excess of 10% of the wall thickness.

3.2 INSTALLATION

A. System components shall be installed using the IR® (Infrared) ½" (20mm) through 12" (315mm) , BCF® (Bead and Crevice Free) ½" (20mm) through 4" (110mm) joining methods according to current installation instructions as delivered in print or documented online at www.gfpiping.com.

An on site installation seminar shall be conducted by GF personnel who are certified to conduct said seminar. Seminar topics shall include all aspects of product installation (storage, set up, support spacing, fusion process, machine care, testing procedure, etc.). At the conclusion of the seminar, all installers will be given a written certification test and will be required to prepare and complete one fusion joint of the type being implemented on the project. Upon successful completion of said test, the installer will be issued a certification card verifying that they have met the requirements of the manufacturer with regards to knowledge of proper product installation and testing methods.

B. Only the following GF Piping Systems LLC fusion units may be used to install the SYGEF® Standard piping system:

For IR Fusion Installation – IR63Plus®, IR225 Plus®, Infrared Butt Fusion Machines

For BCF® Fusion Installations – BCF® Plus

Under this specification, the contractor shall be responsible for the purchase or rental of the proper machine required to meet the intent of the specification and be used for installation of the product on site.

C. Installer shall ensure that all pipe and fittings used for Pure Water Piping are components of the same system. No mixing of various manufacturers pipe and or fittings shall be allowed.

3.3 TESTING

A. The system shall be tested in accordance with the manufacturers' recommendations. Please refer to Georg Fischer's technical handbook for "Pressure Testing" guidelines.

SYGEF® Standard PVDF Specification - IR/BCF

PART 2 - PRODUCTS – MATERIALS

2.01 PURE WATER PIPE AND FITTINGS

A. Polyvinylidene Fluoride pipe shall be manufactured from a virgin resin material, unpigmented and translucent. Dimensions for all sizes shall be in accordance to ISO 10931. Pipe sizes 3/8" (16mm) through 4" (110mm) shall be manufactured to have a pressure rating of 232 psi (16 bar) when measured at 68°F (20°C). Pipe sizes 6in (160mm) through 12" (315mm) shall be manufactured to have a pressure rating of 150 psi (10 bar) when measured at 68°F (20°C). Pipe internal surface finish shall be Ra ≤ 20.0µin (0.5µm).

B. Polyvinylidene Fluoride fittings shall be manufactured from a virgin resin material, unpigmented and translucent. Fittings 3/8" (16mm) through 4" (110mm) shall be manufactured to have a pressure rating of 232 psi (16 bar) when measured at 68°F (20°C). Fitting sizes 6" (160mm) and larger shall be manufactured to have a pressure rating of 150 psi (10 bar) when measured at 68°F (20°C). Fittings shall be available in sizes from 3/8" (16mm) up to 12" (315mm). Fittings shall be manufactured and catalogued for BCF® (Bead and Crevice Free), IR® (Infrared) joining methods.

C. All components of the pipe and fitting system shall conform to the following applicable ASTM Standards, D4101, D 638, D2837, D2122, FM 4910 and shall conform to FDA CFR 21 177.1520 (certificate of conformance to be included with shop drawing submittal), USP 25 Class VI (certificate of conformance to be provided with shop drawing submittal) and ASME-BPE. All pipe and fittings shall be marked with brand name, product description, code number, material, and dimension and pressure rating information. Fittings shall be embossed with a permanent identification during the production process to ensure full traceability.

D. Shall be SYGEF® Piping System as manufactured by GF Piping Systems LLC, Tustin CA.

2.02 VALVES

A. Ball Valves: Ball valves shall be full port, true union end constructed of polyvinylidene fluoride with EPDM or FPM seals available, manufactured for installation in SYGEF® Standard Piping system, Type 546 and as manufactured by GF Piping Systems LLC. Ball valves shall be rated for 232 psi (16 bar) when measured at 68°F (20°C). Pneumatic/Electric valve actuators, if required, shall be supplied by GF Piping Systems LLC to ensure proper system operation.

B. Diaphragm Valves: Diaphragm valves shall be constructed of polyvinylidene fluoride with EPDM or PTFE Seal configurations, manufactured for installation in SYGEF® Standard Piping system, Type 514, 515, 517 and 519 (Zero Static) as manufactured by GF Piping Systems LLC. Diaphragm valves shall be rated for 150 psi (10 bar) when measured at 68°F (20°C). Pneumatic/Electrical valve actuators, if required, shall be supplied by GF Piping Systems LLC to ensure proper system operation.

C. Three Way Ball Valves: Ball valves shall be L-Port/T-Port type constructed of polyvinylidene fluoride with EPDM or FPM seats available, manufactured for installation in SYGEF® Standard Piping system, Type 343 as manufactured by GF Piping Systems LLC. Three way ball valves shall be rated for 150 psi (10 bar) when measured at 68°F (20°C). Pneumatic/Electrical valve actuators, if required, shall be supplied by GF Piping Systems LLC to ensure proper system operation.

D. Butterfly Valves: Butterfly valves shall be constructed of polyvinylidene fluoride with EPDM or FPM seats available, manufactured for installation in SYGEF® Standard Piping system, Type 567 (lug style) or Type 568 (wafer style) as manufactured by GF Piping Systems LLC. Pneumatic/Electrical valve actuators, if required shall be supplied by GF Piping Systems LLC to ensure proper system operation.

2.03 RECIRCULATING LABORATORY FAUCET

A. Recirculating Laboratory Faucet: Shall be constructed of polyvinylidene fluoride and designed to provide a constant fluid flow to the point of use to eliminate dead legs. Faucet shall be Type 530 "Aqua Tap" as manufactured by GF Piping Systems LLC, Tustin CA.

   a. Faucet to be manufactured with needle type flow control for precise metering.

   b. Faucet to be manufactured for deck or wall mounting options.

   c. Recirculating laboratory faucet shall be installed in conjunction with an inline flow diverter (IFD) manufactured of SYGEF® PVDF or PROGEF® Natural PP by GF Piping Systems LLC. The inline flow diverter shall be designed to provide high flow from the distribution main through the faucet for constant water movement. An orifice installed within the inline flow diverter is used to create a differential pressure imbalance which forces water through the faucet with minimal pressure loss. The inline flow diverter(s) shall be installed in the distribution main where shown on the drawings and may serve up to three faucets. The diverters shall be manufactured and catalogued for BCF® (Bead and Crevice Free), IR® (Infrared) or sanitary clamp joining methods.

   d. Faucet shall have a pressure rating of 92 psi (6 bar).

   e. Recirculating laboratory faucet(s) shall be connected to the inline flow diverter using smooth bore 5/8" PFA or PE tubing for design flexibility and simplified piping installations. Tubing shall be connected to faucet(s) and inline flow diverter connection points using easy flare style connection method. Installer shall use GF Piping Systems LLC isolation ball valves installed inline (tubing) or optional emergency shut-off clamps, to facilitate segregation of faucets from the pure water system if required for maintenance or other purposes. Only catalogued AquaTap adaptors, accessories and tools shall be used by the installer.

PART 3 - EXECUTION

3.1 HANDLING

A. Material shall be stored in original packaging and protected from environmental damage until installation. Pipe shall be supported sufficiently to prevent sagging. Care shall be taken not to gouge or otherwise notch the pipe in excess of 10% of the wall thickness.

3.2 INSTALLATION

A. System components shall be installed using the IR® (Infrared), BCF® (Bead and Crevice Free) joining methods according to current installation instructions as delivered in print or documented online at www.gfpiping.com.

An on site installation seminar shall be conducted by GF personnel who are certified to conduct said seminar. Seminar topics shall include all aspects of product installation (storage, set up, support spacing, fusion process, machine care, testing procedure, etc.). At the conclusion of the seminar, all installers will be given a written certification test and will be required to prepare and complete one fusion joint of the type being implemented on the project. Upon successful completion of said test, the installer will be issued a certification card verifying that they have met the requirements of the manufacturer with regards to knowledge of proper product installation and testing methods.

B. Only the following GF Piping Systems LLC fusion units may be used to install the SYGEF® Standard piping system:

For Socket Fusion Installation – SG 110, SG 160 Socket Fusion Machines or MSE Handtool

For IR Fusion Installation – IR63 Plus®, IR225 Plus®, IR-315Plus®, Infrared Butt Fusion Machines

For BCF® Fusion Installations – BCF® Plus

Under this specification, the contractor shall be responsible for the purchase or rental of the proper machine required to meet the intent of the specification and be used for installation of the product on site.

C. Installer shall ensure that all pipe and fittings used for Pure Water Piping are components of the same system. No mixing of various manufacturers pipe and or fittings shall be allowed.

3.3 TESTING

A. The system shall be tested in accordance with the manufacturers' recommendations. Please refer to Georg Fischer's technical handbook for "Pressure Testing" guidelines.

SYGEF® Standard PVDF Specification - Socket

PART 2 - PRODUCTS – MATERIALS

2.01 PURE WATER PIPE AND FITTINGS

A. Polyvinylidene Fluoride pipe shall be manufactured from a virgin resin material, unpigmented and translucent. Pipe sizes 3/8" (16mm) through 2" (63mm) shall be manufactured to have a pressure rating of 232 psi (16 bar) when measured at 68°F (20°C). Pipe internal surface finish shall be Ra ≤ 20.0μin (0.5μm). Pipe shall be manufactured in sizes from 3/8" (16mm) through 2" (63mm).

B. Polyvinylidene Fluoride fittings shall be manufactured from a virgin resin material, unpigmented and translucent. Fittings 3/8" (16mm) through 2" (63mm) shall be manufactured to have a pressure rating of 232 psi (16 bar) when measured at 68°F (20°C). Fittings shall be available in sizes from 3/8" (16mm) up to 2" (63mm).

C. All components of the pipe and fitting system shall conform to the following applicable ASTM Standards, D3222, D 638, D2837, D2122, FM 4910 and shall conform to FDA CFR 21 177.1520 (certificate of conformance to be included with shop drawing submittal), USP 25 Class VI (certificate of conformance to be provided with shop drawing submittal) and ASME-BPE. All pipe and fittings shall be marked with brand name, product description, code number, material, and dimension and pressure rating information. Fittings shall be embossed with a permanent identification during the production process to ensure full traceability.

D. Shall be SYGEF® Piping System as manufactured by GF Piping Systems LLC, Tustin CA.

2.02 VALVES

A. Ball Valves: Ball valves shall be full port, true union end constructed of polyvinylidene fluoride with EPDM or FPM seals available, manufactured for installation in SYGEF® Standard Piping system, Type 546 and as manufactured by GF Piping Systems LLC. Ball valves shall be rated for 232 psi (16 bar) when measured at 68°F (20°C). Pneumatic/Electric valve actuators, if required, shall be supplied by GF Piping Systems LLC to ensure proper system operation.

B. Diaphragm Valves: Diaphragm valves shall be constructed of polyvinylidene fluoride with EPDM or PTFE Seal configurations, manufactured for installation in SYGEF® Standard Piping system, Type 514, 515, 517 and 519 (Zero Static) as manufactured by GF Piping Systems LLC. Diaphragm valves shall be rated for 150 psi (10 bar) when measured at 68°F (20°C). Pneumatic/Electrical valve actuators, if required, shall be supplied by GF Piping Systems LLC to ensure proper system operation.

C. Three Way Ball Valves: Ball valves shall be L-Port/T-Port type constructed of polyvinylidene fluoride with EPDM or FPM seats available, manufactured for installation in SYGEF® Standard Piping system, Type 543 as manufactured by GF Piping Systems LLC. Three way ball valves shall be rated for 150 psi (10 bar) when measured at 68°F (20°C). Pneumatic/Electrical valve actuators, if required, shall be supplied by GF Piping Systems LLC to ensure proper system operation.

D. Butterfly Valves: Butterfly valves shall be constructed of polyvinylidene fluoride with EPDM or FPM seats available, manufactured for installation in SYGEF® Standard Piping system, Type 567 (lug style) or Type 568 (wafer style) as manufactured by GF Piping Systems LLC. Pneumatic/Electrical valve actuators, if required shall be supplied by GF Piping Systems LLC to ensure proper system operation.

2.03 RECIRCULATING LABORATORY FAUCET

A. Recirculating Laboratory Faucet: Shall be constructed of polyvinylidene fluoride and designed to provide a constant fluid flow to the point of use to eliminate dead legs. Faucet shall be Type 530 "Aqua Tap" as manufactured by GF Piping Systems LLC, Tustin CA.

a. Faucet to be manufactured with needle type flow control for precise metering.

b. Faucet to be manufactured for deck or wall mounting options.

c. Recirculating laboratory faucet shall be installed in conjunction with an inline flow diverter (IFD) manufactured of SYGEF® PVDF or PROGEF® Natural PP by GF Piping Systems LLC. The inline flow diverter shall be designed to provide high flow from the distribution main through the faucet for constant water movement. An orifice installed within the inline flow diverter is used to create a differential pressure imbalance which forces water through the faucet with minimal pressure loss. The inline flow diverter(s) shall be installed in the distribution main where shown on the drawings and may serve up to three faucets. The diverters shall be manufactured and catalogued for BCF® (Bead and Crevice Free), IR® (Infrared) or sanitary clamp joining methods.

d. Faucet shall have a pressure rating of 92 psi (6 bar).

e. Recirculating laboratory faucet(s) shall be connected to the inline flow diverter using smooth bore 5/8" PFA or PE tubing for design flexibility and simplified piping installations. Tubing shall be connected to faucet(s) and inline flow diverter connection points using easy flare style connection method. Installer shall use GF Piping Systems LLC isolation ball valves installed inline (tubing) or optional emergency shut-off clamps, to facilitate segregation of faucets from the pure water system if required for maintenance or other purposes. Only catalogued AquaTap adaptors, accessories and tools shall be used by the installer.

PART 3 - EXECUTION

3.1 HANDLING

A. Material shall be stored in original packaging and protected from environmental damage until installation. Pipe shall be supported sufficiently to prevent sagging. Care shall be taken not to gouge or otherwise notch the pipe in excess of 10% of the wall thickness.

3.2 INSTALLATION

A. System components shall be installed using the socket fusion joining methods according to current installation instructions as delivered in print or documented online at www.gfpiping.com.

An on site installation seminar shall be conducted by GF personnel who are certified to conduct said seminar. Seminar topics shall include all aspects of product installation (storage, set up, support spacing, fusion process, machine care, testing procedure, etc.). At the conclusion of the seminar, all installers will be given a written certification test and will be required to prepare and complete one fusion joint of the type being implemented on the project. Upon successful completion of said test, the installer will be issued a certification card verifying that they have met the requirements of the manufacturer with regards to knowledge of proper product installation and testing methods.

B. Only the following GF Piping Systems LLC fusion units may be used to install the SYGEF® Standard piping system:

For Socket Fusion Installation – SG 110, SG 160 Socket Fusion Machines or MSE Handtool

Under this specification, the contractor shall be responsible for the purchase or rental of the proper machine required to meet the intent of the specification and be used for installation of the product on site.

C. Installer shall ensure that all pipe and fittings used for Pure Water Piping are components of the same system. No mixing of various manufacturers pipe and or fittings shall be allowed.

3.3 TESTING

A. The system shall be tested in accordance with the manufacturers' recommendations. Please refer to Georg Fischer's technical handbook for "Pressure Testing" guidelines.

Pressure/Temperature

Long-Term Stress

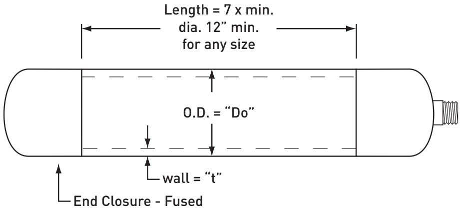
To determine the long-term strength of thermoplastic pipe, lengths of pipe are capped at both ends **(Figure 1)** and subjected to various internal pressures, to produce circumferential stresses that will predict failure in from 10hrs to 50yrs. The test is run according to **ASTM D1598**, "Standard Test for Time to Failure of Plastic Pipe Under Long-Term Hydrostatic Pressure."

The resulting failure points are used in a statistical analysis (outlined in **ASTM D2837**) to determine the characteristic regression curve that represents the stress/time-to-failure relationship of the particular thermoplastic pipe compound. The curve is represented by the equation

$$\log T = a + b \log S$$

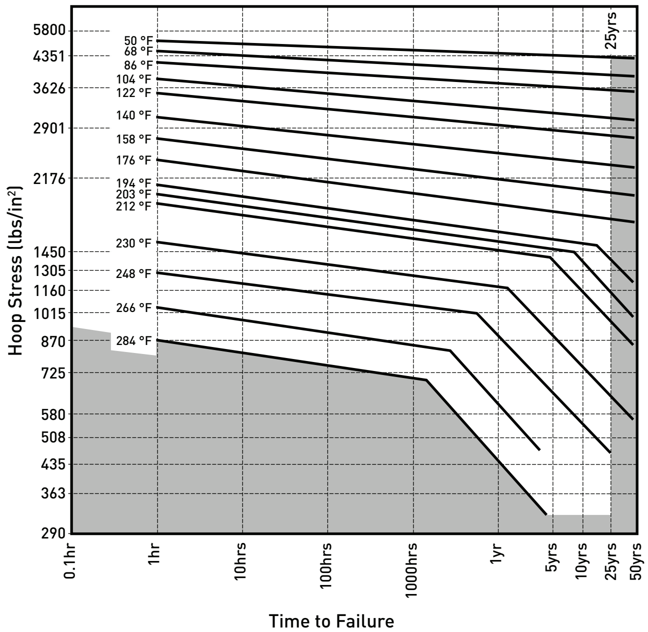
Where a and b are constants describing the slope and intercept of the curve, and T and S are time-to-failure and stress, respectively.

Figure 1



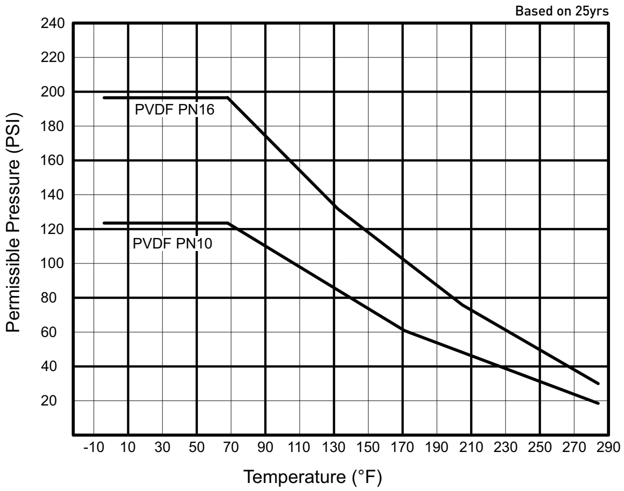
The regression curve may be plotted on log-log paper as shown in **Figure 2** and extrapolated from 5yrs to 25yrs. The stress at 25yrs is known as the hydrostatic design basis (HDB) for that particular thermoplastic compound. From this HDB the hydrostatic design stress (HDS) is determined by applying the service factor multiplier.

Figure 2



Regression Curve
Stress/Time to failure for SYGEF® PVDF

Figure 3



Working Temperature and Pressures for SYGEF® PVDF

Based on 25-year service life. Service Factor C=2.0

Dimensional Pipe Size

Pipe Size Comparison

Table 1

	Outside Dimensions		Wall Thickness		Inside Dimensions	
Nominal Outside Diameter	SYGEF® PVDF PN16	SYGEF® PVDF PN10	SYGEF® PVDF PN16	SYGEF® PVDF PN10	SYGEF® PVDF PN16	SYGEF® PVDF PN10
3/8" - (16mm)	16.0mm	—	1.9mm	—	12.2mm	—
1/2" - (20mm)	20.0mm	—	1.9mm	—	16.2mm	—
3/4"- (25mm)	25.0mm	—	1.9mm	—	21.2mm	—
1" - (32mm)	32.0mm	—	2.4mm	—	27.2mm	—
1 1/4" - (40mm)	40.0mm	—	2.4mm	—	35.2mm	—
1 1/2" - (50mm)	50.0mm	—	3.0mm	—	44.0mm	—
2" - (63mm)	63.0mm	—	3.0mm	—	57.0mm	—
2 1/2" - (75mm)	75.0mm	—	3.6mm	—	67.8mm	—
3" - (90mm)	90.0mm	90.0mm	4.3mm	2.8mm	81.4mm	84.4mm
4" - (110mm)	110.0mm	110.0mm	5.3mm	3.4mm	99.4mm	103.2mm
6" - (160mm)	160.0mm	160.0mm	7.7mm	4.9mm	144.6mm	150.2mm
8" - (200mm)	200.0mm	200.0mm	9.6mm	6.2mm	180.8mm	187.6mm
9" - (225mm)	225.0mm	225.0mm	10.8mm	6.9mm	203.4mm	211.2mm
10" - (250mm)	—	250.0mm	—	7.7mm	—	234.6mm
12" - (315mm)	—	315.0mm	—	9.7mm	—	295.6mm
14" - (355mm)	—	355.0mm	—	10.8mm	—	333.4mm
16" - (400mm)	—	400.0mm	—	12.1mm	—	375.8mm
18" - (450mm)	—	450.0mm	—	13.6mm	—	422.8mm

Calculating Pipe Size

Friction Loss Characteristics

Sizing for any piping system consists of two basic components: fluid flow design and pressure integrity design. Fluid flow design determines the minimum acceptable diameter of pipe and pressure integrity design determines the minimum wall thickness required. For normal liquid service applications an acceptable velocity in pipes is 7 ±3 (ft/sec), with a maximum velocity of 7 (ft/sec) at discharge points.

Pressure drops throughout the piping network are designed to provide an optimum balance between the installed cost of the piping system and the operating cost of the pumps.

Pressure loss is caused by friction between the pipe wall and the fluid, minor losses due to obstructions, change in direction, etc. Fluid pressure head loss is added to elevation change to determine pump requirements.

Hazen and Williams Formula

The head losses resulting from various water flow rates in plastic piping may be calculated by means of the Hazen and Williams formula. **(located in Figure 4):**

C Factors

Tests made both with new pipe and pipe that had been in service revealed that **(C)** factor values for plastic pipe ranged between 160 and 165. Thus the factor of 150 recommended for water in the equation **(located in Figure 4)** is on the conservative side. On the other hand, the **(C)** factor for metallic pipe varies from 65 to 125, depending upon the time in service and the interior roughening. The obvious benefit is that with PVDF piping systems, it is often possible to use a smaller diameter pipe and still obtain the same or even lower friction losses.

Independent variable for these tests are gallons per minute and nominal pipe size (OD). Dependent variables are the velocity friction head and pressure drop per 100ft. of pipe, with the interior smooth.

Figure 4

- V - Fluid Velocity (ft/sec)
- ΔP - Head Loss (lb/in² /100 ft of pipe
- ΔH - Head Loss (ft of water /100 ft of pipe)
- L - Length of Pipe Run (ft)
- L_e - Equivalent Length of Pipe for minor losses (ft)
- D_i - Pipe Inside Diameter (in)
- Q - Fluid Flow (gal/min)
- C - Constant for Plastic Pipes (conservative - 150)

Hazen and Williams Formula:

$$\Delta H = (L + L_e) \cdot \left(\frac{V}{1.318 \cdot C \cdot (\frac{D_i}{4})^{0.63}} \right)^{1.852}$$

Step 1: Solve for V:

$$V = \frac{4Q(0.1337)}{60\pi \left(\frac{D_i}{12} \right)^2}$$

Step 2: Solve for ΔH:

$$\Delta H = (L + L_e) \cdot \left(\frac{V}{1.318 \cdot C \cdot (\frac{D_i}{4})^{0.63}} \right)^{1.852}$$

Step 3: Solve for ΔP:

$$\Delta P = \Delta H / 2.31$$

Flow Rate vs. Friction Loss - SYGEF® PVDF (PN16)

Table 2

Flow Rate (GPM)	V	ΔH	ΔP	V	ΔH	ΔP	V	ΔH	ΔP	V	ΔH	ΔP	Flow Rate (GPM)
	16mm			20mm			25mm			32mm			
0.5	0.89	0.97	0.42										0.5
0.75	1.33	2.05	0.89										0.75
1	1.77	3.49	1.51	1.00	0.88	0.38							1
2	3.54	12.58	5.45	2.01	3.17	1.37	1.17	0.86	0.37				2
3	5.31	26.66	11.54	3.01	6.71	2.90	1.76	1.81	0.78	1.07	0.54	0.23	3
4	7.08	45.42	19.66	4.02	11.43	4.95	2.35	3.09	1.34	1.43	0.92	0.40	4
5	8.85	68.66	29.72	5.02	17.28	7.48	2.93	4.67	2.02	1.78	1.39	0.60	5
6	10.63	96.24	41.66	6.03	24.22	10.48	3.52	6.54	2.83	2.14	1.95	0.84	6
7	12.40	128.04	55.43	7.03	32.22	13.95	4.11	8.70	3.77	2.49	2.59	1.12	7
8	14.17	163.96	70.98	8.03	41.26	17.86	4.69	11.15	4.83	2.85	3.32	1.44	8
9				9.04	51.32	22.22	5.28	13.86	6.00	3.21	4.12	1.79	9
10				10.04	62.38	27.00	5.86	16.85	7.29	3.56	5.01	2.17	10
11				11.05	74.42	32.22	6.45	20.10	8.70	3.92	5.98	2.59	11
12				12.05	87.43	37.85	7.04	23.62	10.22	4.28	7.03	3.04	12
13							7.62	27.39	11.86	4.63	8.15	3.53	13
14							8.21	31.42	13.60	4.99	9.35	4.05	14
15							8.80	35.71	15.46	5.34	10.62	4.60	15
17.5							10.26	47.50	20.56	6.23	14.13	6.12	17.5
20							11.73	60.83	26.33	7.13	18.09	7.83	20
25							14.66	91.96	39.81	8.91	27.35	11.84	25
30										10.69	38.34	16.60	30
35										12.47	51.01	22.08	35
40										14.25	65.32	28.28	40

Note: Caution should be taken when velocities fall within the shaded levels.

Flow Rate vs. Friction Loss - SYGEF® PVDF (PN16)

Table 2 - continued

Flow Rate (GPM)	40mm			50mm			63mm			75mm			Flow Rate (GPM)
	V	ΔH	ΔP	V	ΔH	ΔP	V	ΔH	ΔP	V	ΔH	ΔP	
1	0.21	0.02	0.01										**1**
2.5	0.53	0.11	0.05										**2.5**
5	1.06	0.40	0.17	0.68	0.13	0.06							**5**
10	2.13	1.43	0.62	1.36	0.48	0.21	0.81	0.14	0.06				**10**
15	3.19	3.03	1.31	2.04	1.02	0.44	1.22	0.29	0.13	0.86	0.12	0.05	**15**
20	4.25	5.16	2.23	2.72	1.74	0.75	1.62	0.49	0.21	1.15	0.21	0.09	**20**
25	5.32	7.80	3.38	3.40	2.63	1.14	2.03	0.75	0.32	1.43	0.32	0.14	**25**
30	6.38	10.94	4.73	4.08	3.69	1.60	2.43	1.05	0.45	1.72	0.45	0.20	**30**
35	7.45	14.55	6.30	4.77	4.91	2.13	2.84	1.39	0.60	2.01	0.60	0.26	**35**
40	8.51	18.63	8.07	5.45	6.29	2.72	3.25	1.79	0.77	2.29	0.77	0.33	**40**
45	9.57	23.17	10.03	6.13	7.82	3.39	3.65	2.22	0.96	2.58	0.95	0.41	**45**
50	10.64	28.16	12.19	6.81	9.51	4.12	4.06	2.70	1.17	2.87	1.16	0.50	**50**
55	11.70	33.60	14.55	7.49	11.35	4.91	4.46	3.22	1.39	3.15	1.38	0.60	**55**
60	12.76	39.48	17.09	8.17	13.33	5.77	4.87	3.78	1.64	3.44	1.63	0.70	**60**
65				8.85	15.46	6.69	5.27	4.39	1.90	3.73	1.89	0.82	**65**
70				9.53	17.73	7.68	5.68	5.03	2.18	4.01	2.16	0.94	**70**
75				10.21	20.15	8.72	6.08	5.72	2.48	4.30	2.46	1.06	**75**
80				10.89	22.71	9.83	6.49	6.45	2.79	4.59	2.77	1.20	**80**
95				12.93	31.22	13.52	7.71	8.86	3.84	5.45	3.81	1.65	**95**
100							8.11	9.74	4.22	5.73	4.19	1.81	**100**
125							10.14	14.73	6.38	7.17	6.33	2.74	**125**
150							12.17	20.65	8.94	8.60	8.88	3.84	**150**
175							14.20	27.47	11.89	10.03	11.81	5.11	**175**
200										11.47	15.12	6.55	**200**
225										12.90	18.81	8.14	**225**

Note: Caution should be taken when velocities fall within the shaded levels.

Flow Rate vs. Friction Loss - SYGEF® PVDF (PN16)

Table 2 - continued

Flow Rate (GPM)	V	ΔH	ΔP	V	ΔH	ΔP	V	ΔH	ΔP	V	ΔH	ΔP	Flow Rate (GPM)
	90mm			110mm			160mm			200mm			
20	0.80	0.09	0.04										20
25	0.99	0.13	0.06										25
30	1.19	0.19	0.08	0.80	0.07	0.03							30
35	1.39	0.25	0.11	0.93	0.09	0.04							35
40	1.59	0.32	0.14	1.07	0.12	0.05							40
45	1.79	0.39	0.17	1.20	0.15	0.06							45
50	1.99	0.48	0.21	1.33	0.18	0.08	0.63	0.03	0.01				50
75	2.98	1.01	0.44	2.00	0.38	0.17	0.95	0.06	0.03	0.60	0.02	0.01	75
100	3.98	1.72	0.75	2.67	0.65	0.28	1.26	0.11	0.05	0.81	0.04	0.02	100
125	4.97	2.60	1.13	3.33	0.98	0.43	1.58	0.16	0.07	1.01	0.05	0.02	125
150	5.97	3.65	1.58	4.00	1.38	0.60	1.89	0.22	0.10	1.21	0.08	0.03	150
175	6.96	4.85	2.10	4.67	1.84	0.79	2.21	0.30	0.13	1.41	0.10	0.04	175
200	7.96	6.21	2.69	5.34	2.35	1.02	2.52	0.38	0.16	1.61	0.13	0.06	200
225	8.95	7.73	3.35	6.00	2.92	1.27	2.84	0.47	0.20	1.81	0.16	0.07	225
250	9.95	9.39	4.07	6.67	3.55	1.54	3.15	0.57	0.25	2.02	0.19	0.08	250
275	10.94	11.21	4.85	7.34	4.24	1.84	3.47	0.68	0.30	2.22	0.23	0.10	275
300	11.93	13.16	5.70	8.00	4.98	2.16	3.78	0.80	0.35	2.42	0.27	0.12	300
325	12.93	15.27	6.61	8.67	5.78	2.50	4.10	0.93	0.40	2.62	0.31	0.14	325
350				9.34	6.63	2.87	4.41	1.07	0.46	2.82	0.36	0.16	350
400				10.67	8.48	3.67	5.04	1.37	0.59	3.23	0.46	0.20	400
450				12.00	10.55	4.57	5.67	1.70	0.74	3.63	0.57	0.25	450
500				13.34	12.83	5.55	6.30	2.07	0.90	4.03	0.70	0.30	500
600							7.56	2.90	1.26	4.84	0.98	0.42	600
700							8.82	3.86	1.67	5.64	1.30	0.56	700
800							10.08	4.94	2.14	6.45	1.67	0.72	800
900							11.35	6.15	2.66	7.26	2.07	0.90	900
1000							12.61	7.48	3.24	8.06	2.52	1.09	1000
1200										9.68	3.53	1.53	1200
1400										11.29	4.70	2.03	1400
1600										12.90	6.02	2.61	1600

Note: Caution should be taken when velocities fall within the shaded levels.

Flow Rate vs. Friction Loss - SYGEF® PVDF (PN16)

Table 2 - continued

Flow Rate (GPM)	V	ΔH	ΔP	Flow Rate (GPM)
		225mm		
100	0.64	0.02	0.01	100
150	0.96	0.04	0.02	150
200	1.27	0.07	0.03	200
250	1.59	0.11	0.05	250
300	1.91	0.15	0.07	300
350	2.23	0.20	0.09	350
400	2.55	0.26	0.11	400
500	3.19	0.39	0.17	500
600	3.82	0.55	0.24	600
700	4.46	0.73	0.32	700
800	5.10	0.94	0.41	800
900	5.73	1.17	0.51	900
1000	6.37	1.42	0.62	1000
1150	7.33	1.84	0.80	1150
1300	8.28	2.31	1.00	1300
1450	9.24	2.83	1.22	1450
1600	10.19	3.39	1.47	1600
1750	11.15	4.01	1.73	1750
1900	12.11	4.67	2.02	1900

Note: Caution should be taken when velocities fall within the shaded levels.

Flow Rate vs. Friction Loss - SYGEF® PVDF (PN10)

Table 3

Flow Rate (GPM)	V	ΔH	ΔP	V	ΔH	ΔP	V	ΔH	ΔP	V	ΔH	ΔP	Flow Rate (GPM)
	90mm			110mm			160mm			200mm			
20	0.74	0.07	0.03										20
25	0.93	0.11	0.05										25
30	1.11	0.16	0.07	0.74	0.06	0.03							30
40	1.48	0.26	0.11	0.99	0.10	0.04							40
50	1.85	0.40	0.17	1.24	0.15	0.07	0.58	0.02	0.01	0.37	0.01	0.00	50
75	2.78	0.85	0.37	1.86	0.32	0.14	0.88	0.05	0.02	0.56	0.02	0.01	75
100	3.70	1.44	0.62	2.47	0.54	0.23	1.17	0.09	0.04	0.75	0.03	0.01	100
125	4.63	2.18	0.94	3.09	0.82	0.35	1.46	0.13	0.06	0.94	0.04	0.02	125
150	5.55	3.06	1.32	3.71	1.15	0.50	1.75	0.19	0.08	1.12	0.06	0.03	150
175	6.48	4.07	1.76	4.33	1.53	0.66	2.04	0.25	0.11	1.31	0.08	0.04	175
200	7.40	5.21	2.26	4.95	1.96	0.85	2.34	0.32	0.14	1.50	0.11	0.05	200
225	8.33	6.48	2.80	5.57	2.44	1.05	2.63	0.39	0.17	1.69	0.13	0.06	225
250	9.25	7.88	3.41	6.19	2.96	1.28	2.92	0.48	0.21	1.87	0.16	0.07	250
275	10.18	9.40	4.07	6.81	3.53	1.53	3.21	0.57	0.25	2.06	0.19	0.08	275
300	11.10	11.04	4.78	7.42	4.15	1.80	3.51	0.67	0.29	2.25	0.23	0.10	300
325	12.03	12.80	5.54	8.04	4.81	2.08	3.80	0.78	0.34	2.43	0.26	0.11	325
400				9.90	7.07	3.06	4.67	1.14	0.49	3.00	0.39	0.17	400
450				11.14	8.79	3.81	5.26	1.42	0.61	3.37	0.48	0.21	450
500				12.37	10.69	4.63	5.84	1.72	0.75	3.74	0.58	0.25	500
600							7.01	2.41	1.04	4.49	0.82	0.35	600
700							8.18	3.21	1.39	5.24	1.09	0.47	700
800							9.35	4.11	1.78	5.99	1.39	0.60	800
1000							11.68	6.21	2.69	7.49	2.11	0.91	1000
1200							14.02	8.71	3.77	8.99	2.95	1.28	1200
1400										10.49	3.93	1.70	1400
1600										11.98	5.03	2.18	1600
1800										13.48	6.26	2.71	1800

Note: Caution should be taken when velocities fall within the shaded levels.

Flow Rate vs. Friction Loss - SYGEF® PVDF (PN10)

Table 3 - continued

Flow Rate (GPM)	V	ΔH	ΔP	V	ΔH	ΔP	V	ΔH	ΔP	V	ΔH	ΔP	Flow Rate (GPM)
	225mm			250mm			315mm			355mm			
100	0.59	0.02	0.01										100
150	0.89	0.04	0.02	0.72	0.02	0.01							150
200	1.18	0.06	0.03	0.96	0.04	0.02							200
250	1.48	0.09	0.04	1.20	0.05	0.02	0.75	0.02	0.01				250
300	1.77	0.13	0.06	1.44	0.08	0.03	0.90	0.02	0.01	0.71	0.01	0.01	300
350	2.07	0.17	0.07	1.68	0.10	0.04	1.06	0.03	0.01	0.83	0.02	0.01	350
400	2.36	0.22	0.09	1.92	0.13	0.06	1.21	0.04	0.02	0.95	0.02	0.01	400
500	2.95	0.33	0.14	2.39	0.20	0.09	1.51	0.06	0.03	1.19	0.04	0.02	500
750	4.43	0.69	0.30	3.59	0.42	0.18	2.26	0.14	0.06	1.78	0.08	0.03	750
1000	5.91	1.18	0.51	4.79	0.71	0.31	3.02	0.23	0.10	2.37	0.13	0.06	1000
1250	7.39	1.79	0.77	5.99	1.07	0.46	3.77	0.35	0.15	2.96	0.19	0.08	1250
1300	7.68	1.92	0.83	6.23	1.15	0.50	3.92	0.37	0.16	3.08	0.21	0.09	1300
1350	7.98	2.06	0.89	6.47	1.24	0.54	4.07	0.40	0.17	3.20	0.22	0.10	1350
1400	8.27	2.21	0.96	6.70	1.32	0.57	4.22	0.43	0.19	3.32	0.24	0.10	1400
1500	8.86	2.51	1.09	7.18	1.50	0.65	4.52	0.49	0.21	3.56	0.27	0.12	1500
1750	10.34	3.34	1.44	8.38	2.00	0.87	5.28	0.65	0.28	4.15	0.36	0.16	1750
2000	11.82	4.27	1.85	9.58	2.56	1.11	6.03	0.83	0.36	4.74	0.46	0.20	2000
2250	13.30	5.31	2.30	10.78	3.19	1.38	6.79	1.04	0.45	5.34	0.58	0.25	2250
2500				11.97	3.87	1.68	7.54	1.26	0.54	5.93	0.70	0.30	2500
2750				13.17	4.62	2.00	8.30	1.50	0.65	6.52	0.84	0.36	2750
3000							9.05	1.76	0.76	7.11	0.98	0.43	3000
3500							10.56	2.35	1.02	8.30	1.31	0.57	3500
4000							12.07	3.00	1.30	9.49	1.67	0.72	4000
4500							13.57	3.74	1.62	10.67	2.08	0.90	4500
5000										11.86	2.53	1.09	5000
5500										13.04	3.02	1.31	5500

Note: Caution should be taken when velocities fall within the shaded levels.

Flow Rate vs. Friction Loss - SYGEF® PVDF (PN10)

Table 3 - continued

Flow Rate (GPM)	V	ΔH	ΔP	V	ΔH	ΔP	Flow Rate (GPM)
	400mm			450mm			
400	0.75	0.01	0.01				400
500	0.93	0.02	0.01	0.74	0.01	0.00	500
750	1.40	0.04	0.02	1.11	0.02	0.01	750
1000	1.87	0.07	0.03	1.47	0.04	0.02	1000
1250	2.33	0.11	0.05	1.84	0.06	0.03	1250
1300	2.43	0.12	0.05	1.92	0.07	0.03	1300
1350	2.52	0.12	0.05	1.99	0.07	0.03	1350
1400	2.61	0.13	0.06	2.06	0.08	0.03	1400
1500	2.80	0.15	0.07	2.21	0.09	0.04	1500
1750	3.27	0.20	0.09	2.58	0.11	0.05	1750
2000	3.73	0.26	0.11	2.95	0.15	0.06	2000
2250	4.20	0.32	0.14	3.32	0.18	0.08	2250
2500	4.67	0.39	0.17	3.69	0.22	0.10	2500
2750	5.13	0.47	0.20	4.05	0.26	0.11	2750
3000	5.60	0.55	0.24	4.42	0.31	0.13	3000
3500	6.53	0.73	0.32	5.16	0.41	0.18	3500
4000	7.47	0.93	0.40	5.90	0.53	0.23	4000
4500	8.40	1.16	0.50	6.64	0.65	0.28	4500
5000	9.33	1.41	0.61	7.37	0.80	0.34	5000
5500	10.27	1.69	0.73	8.11	0.95	0.41	5500
6000	11.20	1.98	0.86	8.85	1.12	0.48	6000
6500	12.13	2.30	0.99	9.58	1.29	0.56	6500
7000				10.32	1.48	0.64	7000
7500				11.06	1.69	0.73	7500
8000				11.80	1.90	0.82	8000

Note: Caution should be taken when velocities fall within the shaded levels.

Friction Loss Through Fittings and Valves

Table 4

Fitting or Valve Type	90 Elbow (Molded)	45 Elbow (Molded)	Standard Tee Flow thru run	Standard Tee Flow thru branch	Reducer Bushing (Single Reduction)	Male/Female Adapter	Ball Valve, Full Bore (Full Open)	Type 5-Series Diaphragm Valve	For Industry Standard Elastomer Butterfly Valve (Full Open)
SYGEF® PVDF									
Nominal Pipe Size	Equivalent Length of Pipe (ft.)								
16mm	0.9	0.5	0.6	1.8	—	0.5	0.1	—	1.7
20mm	1.5	0.8	1.0	4.0	1.0	1.0	0.2	8.1	2.5
25mm	2.0	1.0	1.4	5.1	1.1	1.3	0.3	9.6	3.3
32mm	2.7	1.3	1.7	6.0	1.2	1.6	0.3	14.0	4.2
40mm	3.5	1.7	2.3	6.9	1.4	2.2	0.4	11.0	5.0
50mm	4.2	2.1	2.7	8.1	1.7	2.6	0.5	12.0	6.7
63mm	5.5	2.7	4.3	12.0	2.6	3.5	0.8	13.0	10.0
75mm	7.0	3.5	5.1	14.3	3.6	—	—	—	13.3
90mm	8.0	4.0	6.3	16.3	4.4	—	—	—	20.0
110mm	11.0	5.5	8.3	22.1	5.2	—	—	—	26.7
160mm	16.0	8.0	13.0	32.0	7.0	—	—	—	33.3
200mm	20.0	10.0	16.5	40.0	10.0	—	—	—	40.0
225mm	22.5	11.2	18.6	45.0	11.2	—	—	—	46.7
250mm	25.0	12.5	30.5	50.0	12.5	—	—	—	60.7
315mm	31.5	15.7	38.4	63.0	15.7	—	—	—	78.9
355mm	29.8	17.9	36.1	71.6	17.6	—	—	—	—
400mm	33.8	20.3	40.8	80.7	19.8	—	—	—	—
450mm	38.1	22.9	46.0	91.0	22.4	—	—	—	—

Gravity Drain Systems

Flow Rate for Gravity Drain Systems

Drainage flow is caused by gravity due to slope of all drainage piping. Drainage piping is deliberately designed to run only partially full; a full pipe, particularly a stack, could blow out or suck out all the trap seals in the system. For a given type of pipe (friction,) the variables in drainage flow are slope and depth of liquid. When these two factors are known, the flow velocity V and flow rate Q can be calculated. The approximate flow rates and velocities can be calculated as follows:

Q - Flow Rate (gpm)
A - Section Area Pipe (ft^2)
n - Manning Friction Factor 0.009
R - Hydraulic Radius of pipe OD(ft)/4
S - Hydraulic Gradient - Slope (in/ft)

Example Problem:
System Information
Material: 6" (160mm) SYGEF® PVDF (PN10)
Outer Diameter: 6.3in (160.0mm)
Inside Diameter: 5.9in (150.2mm)

FORMULA

$$Q = A \cdot \frac{1.486}{n} \cdot R^{2/3} \cdot S^{1/2}$$

FORMULA

$$V = \frac{1.486}{n} \cdot R^{2/3} \cdot \frac{S^{1/2}}{12}$$

Q - Flow Rate (gpm)
A - Section Area Pipe 0.1906 full = **0.0953** ½full (ft^2)
n - Manning Friction Factor **0.009**
R - Hydraulic Radius of pipe **0.1232** (ft)
S - Hydraulic Gradient - Slope **1/8** (in/ft) = 0.0104
Slope **1/4** (in/ft) = 0.0208
Slope **1/2** (in/ft) = 0.0416

$$Q = .0953 \cdot \frac{1.486}{0.009} \cdot (0.1232)^{2/3} \cdot (0.0208)^{1/2}$$

$$Q = 15.74 \cdot 0.248 \cdot 0.144$$

$$Q = 0.562\ (ft^3/sec)$$

$$Q = 252.2\ (gpm)$$

$$V = \frac{1.486}{0.009} \cdot (0.1232)^{2/3} \cdot \frac{0.144}{12}$$

$$V = 165.1 \cdot 0.248 \cdot 0.012$$

$$V = 0.491\ (ft/sec)$$

Table 5
Approximate Discharge Rates and Velocities in Sloping Drains Flowing Half-Full

Nominal Pipe Diameter	SYGEF® PVDF (PN16)						SYGEF® PVDF (PN10)					
	1/8 (in/ft) Slope		1/4 (in/ft) Slope		1/2 (in/ft) Slope		1/8 (in/ft) Slope		1/4 (in/ft) Slope		1/2 (in/ft) Slope	
	Flowrate (gpm)	Velocity (fps)	Flowrate (gpm)	Velocity (fps)	Flowrate (gpm)	Velocity (fps)	Flowrate (gpm)	Velocity (fps)	Flowrate (gpm)	Velocity (fps)	Flowrate (gpm)	Velocity (fps)
16mm	0.2	0.07	0.3	0.09	0.4	0.13						
20mm	0.5	0.08	0.7	0.11	0.9	0.16						
25mm	1.0	0.09	1.4	0.13	1.9	0.19						
32mm	1.9	0.11	2.6	0.16	3.7	0.22						
40mm	3.7	0.13	5.3	0.19	7.5	0.26						
50mm	6.8	0.15	9.6	0.22	13.5	0.31						
63mm	13.5	0.18	19.0	0.26	26.9	0.36						
75mm	21.4	0.20	30.3	0.29	42.8	0.41						
90mm	34.8	0.23	49.3	0.33	69.7	0.46	38.4	0.24	54.3	0.33	76.7	0.47
110mm	59.3	0.26	83.9	0.37	118.7	0.53	65.6	0.27	92.8	0.38	131.2	0.54
160mm	161.2	0.34	228.0	0.48	322.5	0.68	178.4	0.35	252.3	0.49	356.9	0.69
200mm	292.6	0.39	413.7	0.56	585.1	0.79	322.8	0.40	456.6	0.57	645.7	0.81
225mm	401.6	0.43	567.9	0.60	803.1	0.85	442.8	0.44	626.2	0.62	885.6	0.87
250mm							586.0	0.47	828.7	0.66	1172.0	0.94
315mm							1085.3	0.55	1534.9	0.77	2170.7	1.09
355mm							1496.0	0.59	2115.7	0.84	2992.0	1.18
400mm							2058.6	0.64	2911.3	0.91	4117.2	1.28
450mm							2818.7	0.69	3986.2	0.98	5637.4	1.39

Surge Pressure (Water Hammer)

Surge Pressure (Water Hammer)

Surge pressure, or water hammer, is a term used to describe dynamic surges caused by pressure changes in a piping system. They occur whenever there is a deviation from the steady state, i.e.; when the velocity of the fluid is increased or decreased, and may be transient or oscillating. Waves of positive or negative pressure may be generated by any of the following:

- Opening or closing of a valve
- Pump startup or shutdown
- Change in pump or turbine speed
- Wave action in a feed tank
- Entrapped air

The pressure waves travel along at speeds limited by the speed of sound in the medium, causing the pipe to expand and contract. The energy carried by the wave is dissipated and the waves are progressively damped (see **Figure 5**).

The pressure excess to water hammer must be considered in addition to the hydrostatic load, and this total pressure must be sustainable by the piping system. In the case of oscillatory surge pressures, extreme caution is needed as surging at the harmonic frequency of the system could lead to catastrophic damage.

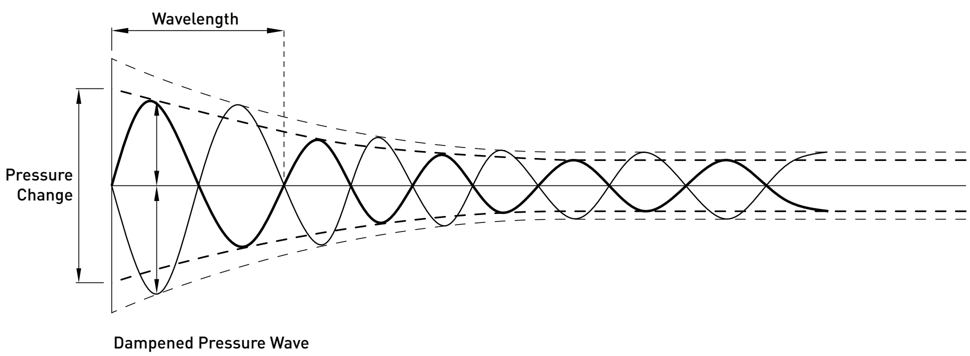


Figure 5

The maximum positive or negative addition of pressure due to surging is a function of fluid velocity, fluid density, bulk fluid density and pipe dimensions of the piping system. It can be calculated using the following steps.

Step 1

Determine the velocity of the pressure wave in pipes.

V_w - Velocity of Pressure Wave (ft./sec)
K - Bulk Density of Water 3.19 x 10^5 (lb/in^2)
n_i - Conversion Factor 1/144 (ft^2/in^2)
δ - Fluid Density of Water 1.937 (slugs/ft^3)

$$V_w = \sqrt{\frac{K}{n_i \cdot \delta}}$$

Step 2

Critical time for valve closure.

$$t_c = \frac{2L}{V_w}$$

t_c - Time for Valve Closure (sec)
V_w - Velocity of Pressure Wave (ft/sec)
L - Upstream Pipe Length (ft)

Step 3

Maximum pressure increase; assume valve closure time is less than the critical closure time and fluid velocity goes to 0.

$$P_i = \delta \cdot V \cdot V_w \, n_i$$

P_i - Maximum Total Pressure (lb/in^2)
δ - Fluid Density ($slugs/ft^3$)
V - Fluid Velocity (ft/sec)
V_w - Velocity of Pressure Wave
n_i - Conversion Factor 1/144 (ft^2/in^2)

Special Consideration

Calculate the Maximum Instantaneous System Pressure.

$$P_{max} = P_i + P_s$$

P_{max} - Maximum System Operating Pressure (lb/in^2)
P_i - Maximum Pressure Increase (lb/in^2)
P_s - Standard System Operating Pressure (lb/in^2)

Cautionary Note

Caution is recommended if P_{max} is greater than the maximum system design pressure multiplied by a safety factor of 2x.

e.g. - Pipe is rated at 150 psi. If P_{max} exceeds 300psi (150psi x 2 safety factor), then precaution must be implemented in case of maximum pressure wave (i.e. water hammer) to prevent possible pipe failure.

Step 4

Determine the Maximum System Pressure Increase with Gradual Valve Closure

P_g - Gradual Pressure Increase with Valve Closure (lb/in^2)
L - Upstream Pipe Length (ft.)
V - Fluid Velocity (ft./sec)
n_i - Conversion Factor 1/144 (ft^2/in^2)
t_c - Time of Valve Closure (sec)

$$P_g = \frac{2 \cdot \delta \cdot L \cdot V \cdot n_i}{t_v}$$

Example Problem

A water pipeline from a storage tank is connected to a master valve, which is hydraulically actuated with an electrical remote control. The piping system flow rate is 300 (gal/min) with a velocity of 4 (ft./sec); thus requiring a 6" (160mm) nominal pipeline. The operating pressure of the system will be 50 (lb/in^2), the valve will be 500 (ft.) from the storage tank and the valve closing time is 2.0 (sec). Determine the critical time of closure for the valve, and the internal system pressure should the valve be instantaneously or suddenly closed vs. gradually closing the valve (10 times slower).

Pipe Details			
System Information		**Other Information**	
Material:	**6" (160mm) SYGEF® (PVDF) PN10**	Bulk Water Density **(K)**	**3.19×10^5 (lb/in^2)**
Flow Rate:	**300 (gal/min)**	Fluid Density **(δ)**	**1.937 ($slugs/ft^3$)**
Pipeline Length:	**500 (ft)**	Valve Closing Time	**2.0 (sec)**
Operating Pressure:	**50 (lb/in^2)**	Water Velocity	**3.5 (ft/sec)**

Step 1 - Velocity of Pressure Wave

Determine the Velocity of the Pressure Wave

V_w - Velocity of Pressure Wave (ft/sec)
K - Bulk Density of Water **3.19 x 10⁵** (lb/in²)
n_i - Conversion Factor **1/144** (ft²/in²)
δ - Fluid Density **1.937** (slugs/ft³)

$$V_w = \sqrt{\frac{K}{n_i \cdot \delta}} \qquad V_w = \sqrt{\frac{3.19 \times 10^5}{\frac{1}{144} \cdot 1.937}}$$

$$V_w = 4870 \text{ (ft/sec)}$$

Step 2 - Critical Valve Closure Time

Determine the Critical Closure Time

t_c - Critical Closure Time (sec)
V_w - Velocity of Pressure Wave **4870** (ft/sec)
L - Upstream Pipe Length **500** (ft)

$$t_c = \frac{2L}{V_w} \qquad t_c = \frac{2 \cdot 500}{4870}$$

$$t_c = 0.2 \text{ (sec)}$$

Step 3 - Maximum Pressure Increase

Determine the Maximum Pressure Increase; Assume: Valve Closure Time < Critical Closure Time t_c and Fluid Velocity goes to 0.

P_i - Maximum Pressure Increase (lb/in²)
δ - Fluid Density **1.937** (slugs/ft³)
V - Fluid Velocity **4** (ft/sec)
V_w - Velocity of Pressure Wave **4870** (ft/sec)
n_i - Conversion Factor **1/144** (ft²/in²)

$$P_i = \delta \cdot V \cdot V_w \, n_i \qquad P_i = \frac{1.937 \cdot 4 \cdot 4870}{144}$$

$$P_i = 262 \text{ (lb/in}^2\text{)}$$

Consideration: Maximum Instantaneous System Pressure

Determining the Maximum Instantaneous System Pressure: Caution is recommended if P_{max} is greater than the Maximum System Operating Pressure multiplied by a 2x Service Factor.

P_{max} - Maximum Instantaneous Operating Pressure (lb/in²)
P_i - Valve Pressure (instantaneous) (lb/in²)
P_s - Standard System Operating Pressure (lb/in²)

In this case, 6" (160mm) SYGEF® PVDF pipe is rated at 150psi. Therefore, the system design is outside safety limits (300psi max).

$$P_{max} = P_i + P_s \qquad P_{max} = 262 + 50$$

$$P_{max} = 312 \text{ (lb/in}^2\text{)}$$

Expansion/Contraction

Allowing for Length Changes in PVDF Pipelines

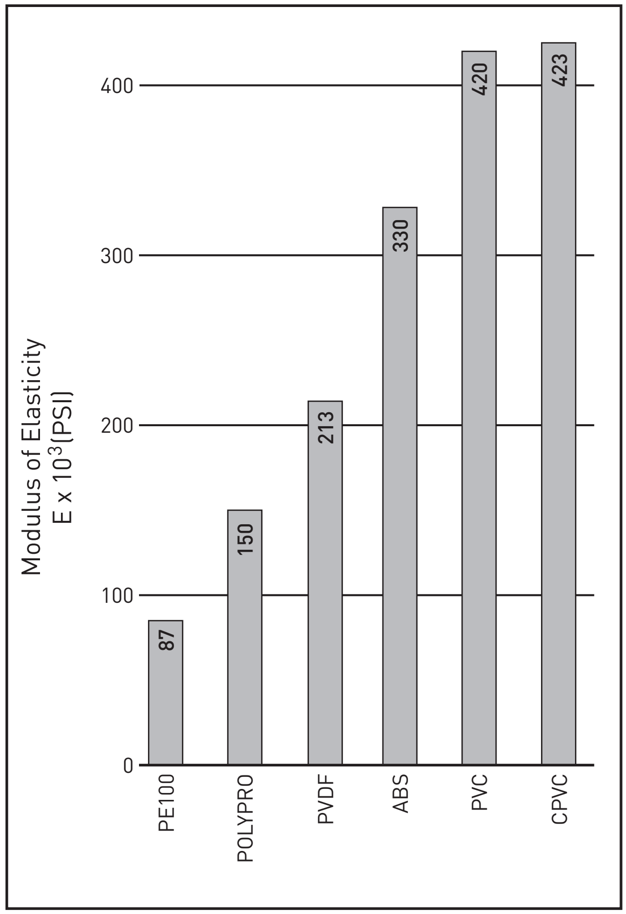
Variations in temperature cause greater length changes in thermoplastic materials than in metals. In the case of above ground, wall or duct mounted pipe work, particularly where subjected to varying working temperatures, it is necessary to make suitable provision for length changes in order to prevent additional stresses.

Calculation and Positioning of Flexible Sections

It is possible to take advantage of the very low modulus of elasticity of PVDF by including special sections of pipe which compensate thermal length changes. The length of the flexible section mainly depends upon the pipe diameter and the extent of the length change to be compensated. In order to simplify planning and installation, the third influencing factor— the pipe wall temperature —is not taken into account, particularly as installation usually takes place in the temperature range between 37°F (3°C) and 77°F (25°C).

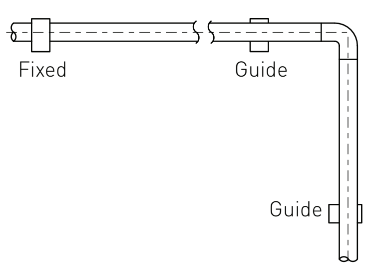
Where the pipe work changes direction or branches off, there is always a natural flexible section.

There are two primary methods of controlling or compensating for thermal expansion of plastic piping systems: taking advantage of offsets and changes of direction in the piping and expansion loops.

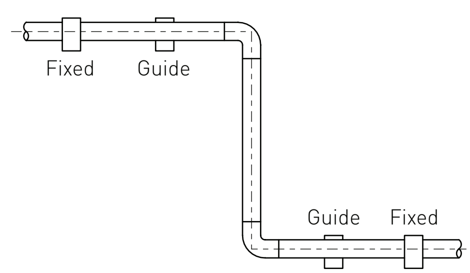


Type 1 - Offsets/Changes in Direction

Most piping systems have occasional changes in directions which will allow the thermally included length changes to be taken up in offsets of the pipe beyond the bends. Where this method is employed, the pipe must be able to float except at anchor points.



Changes in Direction

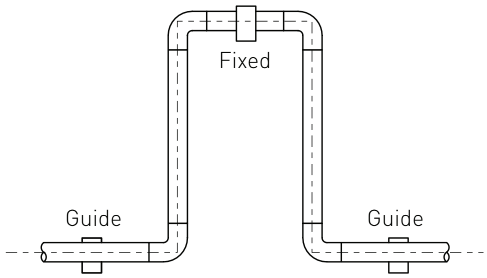


Offsets

+GF+

Type 2 -Expansion Loops

For expansion loops the flexible section is broken into two offsets close together. By utilizing the flexible members between the legs and 4 elbows the "a" length is slightly shorter than the "a" in the standalone offset.



Expansion Loop

Determining the Length Change (ΔL) (Example 1)

In order to determine the length of flexible section (a) required, the extent of the length change must be ascertained first of all, by means of the following formula where

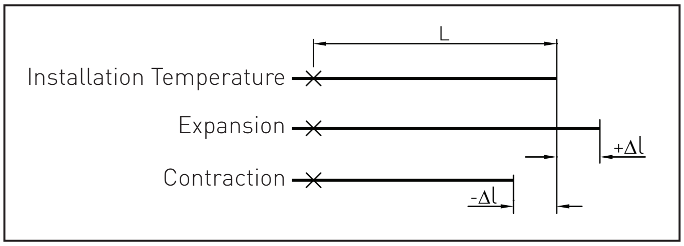
$$\Delta L = L \cdot \Delta T \cdot \delta \qquad \text{(inch) = (inch)} \cdot (^{\circ}\text{F}) \cdot \text{(inch/inch}^{\circ}\text{F)}$$

ΔL = Length change in inches

L = Length in inches of the pipe or pipe section where the length change is to be determined

ΔT = Difference between installation temperature and maximum or minimum working temperature in °F

δ = Coefficient of linear expansion - 0.000078 in/in°F



Important:

If the operating temperature is higher than the installation temperature, then the pipe becomes longer. If, on the other hand, the operating temperature is lower than the installation temperature, then the pipe contracts its length. The installation temperature must therefore be incorporated into the calculation, as well as the maximum and minimum operating temperatures.

Problem

The procedure is explained using a coolant pipe as an example: Length of the pipe from the fixed point to the branch where the length change is to be taken up: L = 315in

Temperature Requirements

Installed Temp	Operating Temp	Defrost/Cleaning
T_v = 73°F	T_1= 40°F	T_2= 95°F

Difference in Contraction Temperature

$\Delta T_1 = T_v - T_1$ = 73°F - 40°F = 33°F

Difference in Expansion Temperature

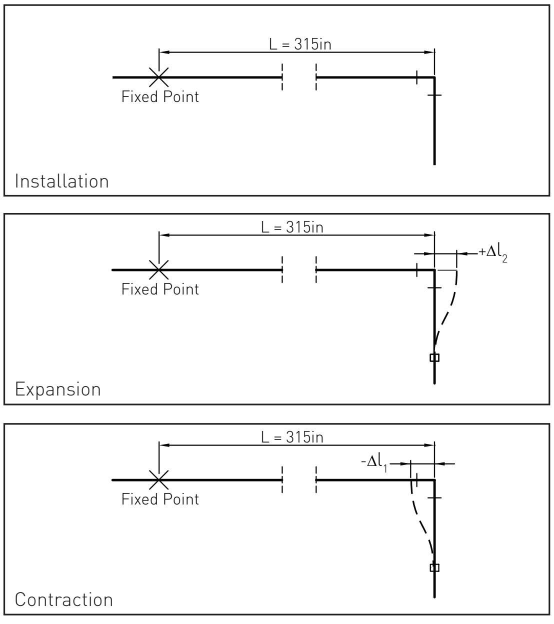
$\Delta T_2 = T_2 - T_v$ = 95°F - 73°F = 22°F

Contraction during service with coolant

$-\Delta L_1 = L \cdot \Delta T_1 \cdot \delta$ = 315in · 33 · (0.000078) = 0.81in

Expansion during defrosting and cleaning

$+\Delta L_2 = L \cdot \Delta T_2 \cdot \delta$ = 315in · 22 · (0.000078) = 0.54in



Length Change (ΔL) in Inches

Table 6

Temperature Change in (°F)	Length of Pipe Section (ft)																			
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
5			0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.5
10		0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.9	0.9
15	0.1	0.1	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1.0	1.1	1.1	1.2	1.3	1.3	1.4
20	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
25	0.1	0.2	0.4	0.5	0.6	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.5	1.6	1.8	1.9	2.0	2.1	2.2	2.3
30	0.1	0.3	0.4	0.6	0.7	0.8	1.0	1.1	1.3	1.4	1.5	1.7	1.8	2.0	2.1	2.2	2.4	2.5	2.7	2.8
35	0.2	0.3	0.5	0.7	0.8	1.0	1.1	1.3	1.5	1.6	1.8	2.0	2.1	2.3	2.5	2.6	2.8	2.9	3.1	3.3
40	0.2	0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.7
45	0.2	0.4	0.6	0.8	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.2	3.4	3.6	3.8	4.0	4.2
50	0.2	0.5	0.7	0.9	1.2	1.4	1.6	1.9	2.1	2.3	2.6	2.8	3.0	3.3	3.5	3.7	4.0	4.2	4.4	4.7
55	0.3	0.5	0.8	1.0	1.3	1.5	1.8	2.1	2.3	2.6	2.8	3.1	3.3	3.6	3.9	4.1	4.4	4.6	4.9	5.1
60	0.3	0.6	0.8	1.1	1.4	1.7	2.0	2.2	2.5	2.8	3.1	3.4	3.7	3.9	4.2	4.5	4.8	5.1	5.3	5.6
65	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.3	3.7	4.0	4.3	4.6	4.9	5.2	5.5	5.8	6.1
70	0.3	0.7	1.0	1.3	1.6	2.0	2.3	2.6	2.9	3.3	3.6	3.9	4.3	4.6	4.9	5.2	5.6	5.9	6.2	6.6
80	0.4	0.7	1.1	1.5	1.9	2.2	2.6	3.0	3.4	3.7	4.1	4.5	4.9	5.2	5.6	6.0	6.4	6.7	7.1	7.5
90	0.4	0.8	1.3	1.7	2.1	2.5	2.9	3.4	3.8	4.2	4.6	5.1	5.5	5.9	6.3	6.7	7.2	7.6	8.0	8.4
100	0.5	0.9	1.4	1.9	2.3	2.8	3.3	3.7	4.2	4.7	5.1	5.6	6.1	6.6	7.0	7.5	8.0	8.4	8.9	9.4

Determining the Length of the Flexible Section (a) (Example 2)

The values required to determine the length of the flexible **(a)** section are:

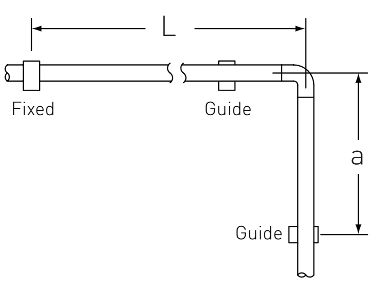
The maximum length change ΔL in comparison with the zero position during installation, (which can be either an expansion or a contraction), and the pipe diameter **(d)**.

If values ΔL and **(d)** are known, **Table 7** shows the length of flexible section **(a)** required.

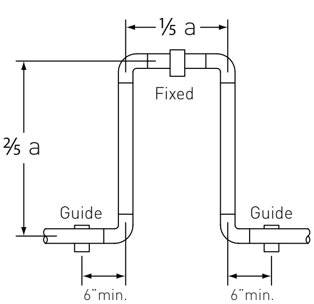
Formula for Flexible Sections (a)

$$a = k\sqrt{\Delta L \cdot d}$$

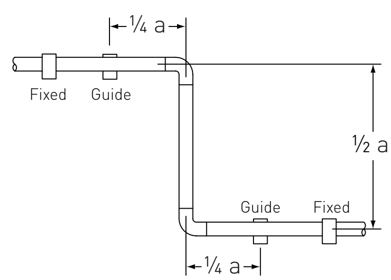
a = Length of Flexible Section
k = Constant (k = 21.7 PVDF)
ΔL = Change in Length
d = Outside Diameter of Pipe



Change of Direction



Expansion Loop



Offset

Table 7: Flexible Sections (a) in Inches where ΔT ≤ 20°F

Values shown are minimum values.

	PVDF Nominal Pipe Diameter																
Length Change - ΔL (in)	20mm	25mm	32mm	40mm	50mm	63mm	75mm	90mm	110mm	160mm	200mm	225mm	250mm	315mm	355mm	400mm	450mm
0.1	6	7	8	9	10	11	12	13	14	17	19	20	22	24	26	27	29
0.2	9	10	11	12	14	15	17	18	20	24	27	29	30	34	36	39	41
0.3	11	12	13	15	17	19	20	22	25	30	33	35	37	42	44	47	50
0.4	12	14	15	17	19	22	24	26	29	34	39	41	43	48	51	54	58
0.5	14	15	17	19	22	24	26	29	32	39	43	46	48	54	57	61	65
0.6	15	17	19	21	24	26	29	32	35	42	47	50	53	59	63	67	71
0.7	16	18	20	23	25	29	31	34	38	46	51	54	57	64	68	72	76
0.8	17	19	22	24	27	31	33	37	40	49	54	58	61	68	73	77	82
0.9	18	20	23	26	29	32	35	39	43	52	58	61	65	72	77	82	87
1.0	19	22	24	27	30	34	37	41	45	54	61	65	68	76	81	86	91
2.0	27	30	34	39	43	48	53	58	64	77	86	91	96	108	115	122	129
3.0	33	37	42	47	53	59	65	71	78	94	105	112	118	132	141	149	158
4.0	39	43	49	54	61	68	75	82	90	109	122	129	136	153	162	172	183
5.0	43	48	54	61	68	76	83	91	101	122	136	144	152	171	181	193	204
6.0	47	53	60	67	75	84	91	100	111	133	149	158	167	187	199	211	224
7.0	51	57	64	72	81	90	99	108	119	144	161	171	180	202	215	228	242
8.0	54	61	69	77	86	97	106	116	128	154	172	183	193	216	229	244	258
9.0	58	65	73	82	91	103	112	123	135	163	183	194	204	229	243	258	274
10.0	61	68	77	86	96	108	118	129	143	172	193	204	215	242	257	272	289

Installation Hints

The length changes in pipe sections should be clearly controlled by the arrangement of fixed brackets. It is possible to distribute the length changes in pipe sections using proper positioning of fixed brackets (see adjoining examples).

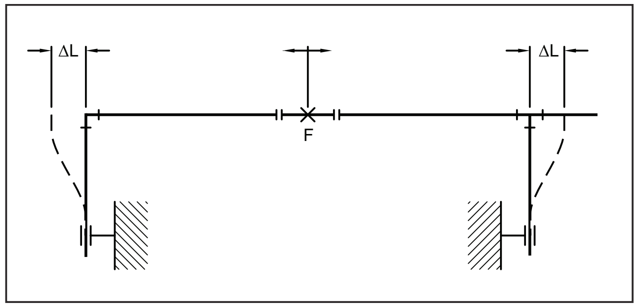
If it is not possible to include a flexible section at a change of direction or branch, or if extensive length changes must be taken up in straight sections of pipe work, expansion loops may also be installed. In this case, the length change is distributed over two flexible sections.

Note

To eliminate bilateral expansion thrust blocks are recommended at intersections.

Example:

For a 2" (63mm) PVDF expansion loop where Δt=20°F, the length change of **0.82in** would require a flexible section length of **a = 10in (ΔL = 0.82/2)**. A single flexible section on the other hand, would need to be **20in. (ΔL = 0.82)** in length.



Pre-Stressing

In particularly difficult cases, where the length changes are large and acting in one direction only, it is also possible to pre-stress the flexible section during installation, in order to reduce the length of **(a)**. This procedure is illustrated in the following example:

Installation conditions

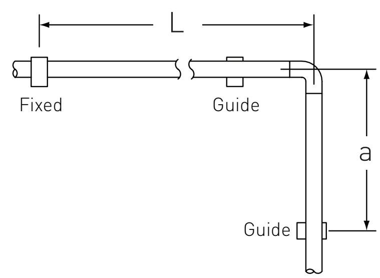
L = **315in.**

d = **63mm.** (nominal)

Installation temperature: **73°F**

Max. working temperature: **95°F**

Material: SYGEF® PVDF



1 . Length change

+ΔL = L • ΔT • ∝ = 315 • 22 • (0.000078) = 0.54in.

2. Flexible section required to take up length change of ΔL = 0.54in according to **Table 7**:

a = approx. 36in.

3. If, on the other hand, the flexible section is pre-stressed to ΔL/2, the required length of flexible section is reduced to approx. 48in. The length change, starting from the zero position, then amounts to

±ΔL/2 = 0.54in/2 = 0.27in.

a = approx. 25in. (per Table 7)

In special cases, particularly at high working temperatures, pre-stressing of a flexible section improves the appearance of the pipeline in service, as the flexible section is less strongly deflected.

Installation

The Incorporation of Valves

Valves should be mounted as directly as possible; they should be formed as fixed points. The actuating force is thus transmitted directly, and not through the pipeline. Any changes in length which arise can be prevented with the appropriate fixed points, before and after the valve.

For safe mounting of plastic valves, GF valves are equipped with metal threaded inserts for direct mounted installation.

Vibration Dampeners

There are two principal ways to control stress caused by vibration. You can usually observe the stability of the system during initial operation and add restraints or supports as required to reduce effects of equipment vibration. Where necessary restraint fittings may be used to effectively hold pipe from lifting or moving laterally.

In special cases where the source of vibration is excessive (such as that resulting from pumps running unbalanced), an elastomeric expansion joint or other vibration absorber may be considered. This may be the case at pumps where restricting the source of vibration is not recommended.

The Installation of Pipe Work under Plaster or Embedded in Concrete

Padded Pipe Work

Where pipe work installed under plaster or embedded in concrete changes direction or branches off, the flexible section under consideration must be padded along the length **(a)**, which is based on the calculated length change. The accompanying tees or elbows must, of course, also be included in the padding. Only flexible materials, such as glass wool, mineral wool, foam plastic or similar may be used for padding.

Pipe Bracket Support Centers and Fixation of Plastic Pipelines

General Pipe Supports and Brackets

PVDF pipelines need to be supported at specific intervals, depending upon the material, the average pipe wall temperature, the specific gravity of the medium, and the diameter and wall thickness of the pipe. The determination of the pipe support centers has been based on the permissible amount of deflection of the pipe between two brackets. The pipe bracket centers given in **Table 8** are calculated on the basis of a permissible deflection of max. 0.01 in (0.25 cm) between two brackets.

Pipe Bracket Spacing in the Case of Fluids with Specific Gravity ≤ 1.0 (62.4 Lb/Ft^3)

Where fluids with a specific gravity exceeding 1.0 (62.4 lb/ft^3) are to be conveyed, the pipe bracket centers given in **Table 8** must be divided by the specific gravity of the fluid, resulting in shorter distances between the supports.

Installation of Closely Spaced Pipe Brackets

A continuous support may be more advantageous and economical than pipe brackets for small diameter horizontal pipe work, especially in a higher temperature range. Installation in a "V"-or "U"-shaped support made of metal or heat-resistant plastic material has proven satisfactory.

Pipe Bracket Requirements

When mounted, the inside diameter of the bracket must be greater than the outside diameter of the pipe, in order to allow length changes of the pipe at the specified points. The inside edges of the pipe bracket must be formed in such a way that no damage to the pipe surface is possible. GF pipe brackets meet these requirements. They are made of plastic and may be used under rugged working conditions and also in areas where the pipe work is subjected to the external influence of aggressive atmospheres or media. GF pipe brackets are suitable for PVC, CPVC, PE, PP and PVDF pipes.

Arrangement of Fixed Brackets

If the pipe bracket is positioned directly beside a fitting, the length change of the pipeline is limited to one direction only (one-sided fixed point).

If it is, as in most cases, necessary to control the length change of the pipeline in both directions, the pipe bracket must be positioned between two fittings. The pipe bracket must be robust and firmly mounted in order to take up the force arising from the length change in the pipeline. Hanger type brackets are not suitable as fixed points.

General Pipe Supports and Brackets for Liquids with a Specific Gravity ≤ 1.0 (62.4 lb/ft^3)

Table 8

Pipe Size (mm)	Size (inch)	Pipe Bracket Intervals L (ft.) for SYGEF® PVDF						
		≤65°F	104°F	140°F	176°F	212°F	248°F	284°F
20mm	1/2	2.8	2.5	2.3	2.0	1.6	1.5	1.3
25mm	3/4	3.1	2.8	2.5	2.2	2.0	1.6	1.5
32mm	1	3.6	3.3	3.0	2.6	2.3	2.0	1.6
40mm	1 1/4	3.9	3.6	3.3	3.0	2.5	2.1	1.8
50mm	1 1/2	4.6	4.3	3.8	3.3	3.0	2.5	2.0
63mm	2	4.6	4.3	3.9	3.6	3.1	2.6	2.1
75mm	2 1/2	4.9	4.6	4.3	3.9	3.4	2.8	2.3
90mm	3	5.2	4.9	4.6	4.3	3.6	3.1	2.8
110mm	4	5.9	5.6	5.1	4.8	4.1	3.6	3.1
160mm	6	7.1	6.7	6.1	5.6	5.1	4.4	3.8
200mm	8	7.9	7.4	6.9	6.2	5.6	4.9	4.3
225mm	9	8.4	7.9	7.2	6.9	5.9	5.2	4.6
250mm	10	8.7	8.2	7.5	7.2	6.2	5.6	4.9
315mm	12	9.8	9.4	8.5	8.2	7.1	6.2	5.4
355mm	14	10.7	9.6	8.7	7.8	7.0	6.3	5.7
400mm	16	11.6	10.4	9.4	8.5	7.6	6.8	6.2
450mm	18	12.8	11.5	10.4	9.3	8.4	7.6	6.8

Note, general rule of thumb: Pipe spacing can be adjusted by dividing the support spacing by the specific gravity.

Example: 63mm pipe carrying media with a specific gravity of 1.6 – 4.6ft divided by 1.6 = approx. 2.8ft centers.

Shear Force of Restraint Fittings (Fixation Brackets)

Pipe Size (mm)	Size (inch)	Shear Force in lbs		
		@ 68°F (20°C)	@ 104°F (40°C)	@ 140°F (60°C)
20mm	1/2	1798	1506	1214
25mm	3/4	2158	1798	1461
32mm	1	2697	2248	1798
40mm	1 1/4	3147	2698	2023
50mm	1 1/2	3821	3147	2473
63mm	2	4496	3821	2922
75mm	2 1/2	8317	6969	5620
90mm	3	9442	7868	6294
110mm	4	11015	9217	7418

Fusion Joining Technology

Reliable Fusion Joining

Assembly and joining of this system is performed by heat fusion. Fusion joints are made by heating and melting the pipe and fitting together. This type of joint gives a homogeneous transition between the two components without the lowering of chemical resistance.

Three different fusion methods for Georg Fischer's SYGEF® PVDF Piping Systems are available and commonly used in today's demanding applications. These include socket fusion, Infrared (IR) butt fusion and BCF® (Bead & Crevice Free) fusion.

Socket Fusion Joining

Socket Fusion Joining can be used to join socket fusion fittings available in sizes 3/8"(16mm) to 2"(63mm). The socket fusion method of joining uses a heated non-stick "female" bushing to melt the outside of the pipe end and a heated non-stick "male" bushing to heat the inside of the corresponding size of fitting. After several seconds, when the outside of the pipe and the inside of the fitting are melted, the bushings are removed and the pipe is pushed into the fitting. Due to the large area of pipe to fitting contact (3-5 times the cross sectional area of the pipe), the resulting joint is actually several times stronger than the pipe itself. The pipe and fittings for this system are also manufactured to have an interference fit; because of this interference it is not possible to slide a fitting over the pipe without the use of heat to melt the surface to be joined. This feature prevents the possibility of inadvertently leaving a joint unfused, and more importantly causes displacement of some material during fusion thereby guaranteeing a high strength, reliable, reproducible joint.

Advantages

- Fast fusion times
- Low Installation Cost
- Easiest fusion method
- Corrosion resistant

IR Plus® Infrared Butt Fusion Joining

IR Plus® Infrared Butt Fusion Joining is an ideal method to join IR fusion fittings in the size range of up to 18" (450mm) to achieve the maximum joint consistency.

Using the process-controlled fusion machinery, high-strength butt fusion joints can be made with many advantages over the conventional, pressure type butt fusion methods. A non-contact IR heating plate is used, along with a predetermined overlap to join the pipe (or fitting) ends together eliminating the potential for operator error. Reliable, reproducible, high strength joints with smaller internal and external beads can be achieved.

Advantages

- Non-contact heating
- Smaller internal and external beads repeatability
- Low stress joint
- Ease of operation due to fully automated fusion machinery
- Automatic fusion joining record (if desired) using optional printer or PC download

BCF® (Bead & Crevice Free) Fusion Joining

The Georg Fischer BCF® (Bead and Crevice Free) joining system produces bead and crevice free joints for SYGEF® PVDF (polyvinylidene fluoride) piping. It is used where there is extreme concern about the presence of small beads or crevices in the piping system. Such applications can be found in the Semiconductor, Pharmaceutical, and Food and Beverage Industries.

The BCF® joining machine automatically clamps and aligns the pipe and fitting, and produces the seamless joint by a proprietary heatfusion method. The machine's electronic logic circuits provide temperature monitoring and heat sensing to automatically produce the proper weld for the particular pipe size. The BCF® system is offered in 1/2" (20mm) through 4" (110mm) pipe diameters; with 90° elbows, T's, unions, diaphragm valves, zero static diaphragm valves, reducers (both concentric and eccentric), and flange adapters.

Advantages

- Completely smooth inner surface
- Low stress joint
- Ease of operation due to fully automated fusion machinery
- Automatic fusion joining record (if desired) using optional printer or PC download

Socket Fusion

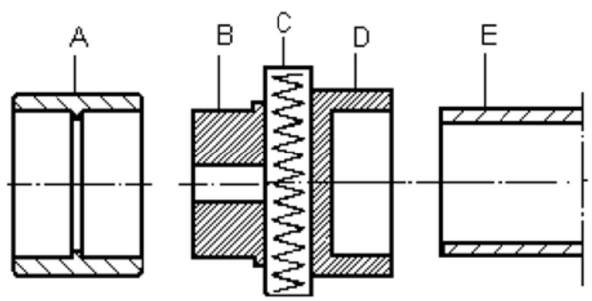
Socket Fusion Joining Method

In this form of fusion jointing, which requires heating tools, the pipe end is inserted into the socket of the fitting; no additional material is used. The pipe end and fitting socket are heated to fusion temperature using a heating bush and a heating spigot, respectively, and are then pushed together.

Details of the requirements for machines and equipment used for fusion jointing thermoplastics are contained in DVS 2208 Part 1.

The pipe end, fitting socket and heating tools correspond in such a way that the necessary jointing pressure is attained during jointing, resulting in a homogeneous joint.

The Principle of Fusion Joining



A. Fitting
B. Heating Spigot
C. Heating Element
D. Heating Bush
E. Pipe

General requirements

The basic rule is that only similar materials can be fusion jointed. For best results, only components which have a density between 0.061 lb/in^3 and 0.065 lb/in^3 and a melt flow index in the range from 2.2x10^{-3} lb/10min to 5.5x10^{-2} lb/10min should be fusion jointed. This requirement is met by PVDF socket fusion fittings from GF.

In socket fusion, attention must be paid to the minimum wall thicknesses of the pipes. The following table in this introduction contains details.

Tools required

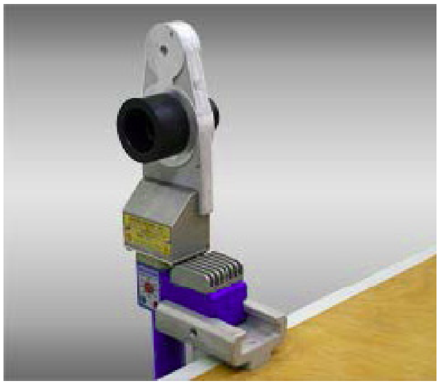
Apart from the tools normally used in plastic piping construction, such as pipe cutters or a saw with a cutting guide, the socket fusion jointing method requires certain special tools.

Important: The tools described here may be used for GF socket fusion fittings made of PVDF, PP and PE.

Pipe peeling and chamfering tool

This is used to calibrate the pipe end. This reduces the force exerted to push the pipe into the heating bush, while preventing damage to the surface coating of the heating bush. At the same time the pipe end is chamfered and the insertion depth marked.

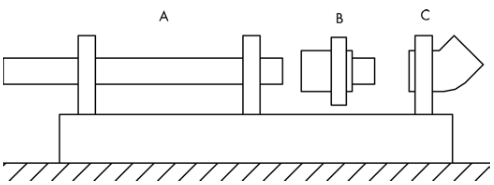
Note: Further information on the fusion jointing equipment hire service and training courses are available from GF.



Heating element for manual fusion jointing

The element is heated electrically. The heating bush and spigot are removable. A separate pair is required for each pipe size.

Important: The surfaces of the heating tool which come into contact with the pipe or the fitting must have a non-stick coating.



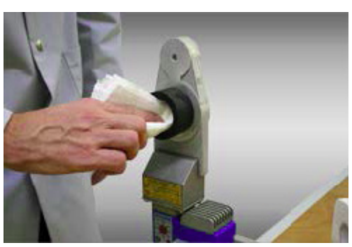
A. Pipe
B. Heating Element
C. Fitting

Fusion jointing machine

A fusion jointing machine is recommended for fittings with a diameter of d = 1 1/2" (50mm) or more. It is also better to use a machine for smaller joints if there is a large number to be made.

The machine should be set up and operated according to its manufacturer's instructions. The procedure detailed below (including the preparation) is for fusion jointing with the help of a manual jointing tool.

Set the temperature of the heating tool to 500°F (260°C). Check the temperature. The fusion temperature must be between 482°F (250°C) and 518°F (270°C). To test the thermostat, check the fusion temperature from time to time on the outside of the heating bush, using a fast acting thermoprobe or tempil sticks [487°F (253°C) or 525°F (274°C)]. This is particularly important when working in strong wind.



Use a clean cloth or dry paper to clean the heating bush and the heating spigot. The tools must be cleaned after making each fusion joint.

Cut the pipe square using a cutter for plastic pipes and deburr the inside edges with a knife.

Make sure that the tools and pipes are clean and grease-free even beyond the fusion zone; if necessary, clean with a cleaning fluid.

For pipes ranging in size from d = 1/2" (20mm) to d = 2" (63mm) peel the pipe end until the blades are flush with the pipe end.

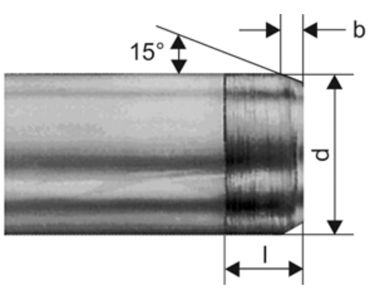
Should ovality of the pipe prevent the peeling tool from being properly applied, the pipe must first be rounded (e.g. in a vice or with a screw clamp).

Use a scraper to complete the peeling of any area where ovality impairs the effectiveness of the peeling tool.

If the peeling tool can be pushed onto the pipe without removing any material, then the dimensional accuracy of the pipe's outside diameter and of the peeling tool should be checked.

Contact GF for resharpening or replacing the blades. Should this work be carried out independently, use a mandrel gauge to adjust the blades to the following diameters.

Outside Pipe Diameter in (mm)	Peeled Diameter (mm)	Peeled Length (mm)
3/8" (16mm)	15.85 to 15.95	13
1/2" (20mm)	19.85 to 19.95	14
3/4" (25mm)	24.85 to 24.95	16
1" (32mm)	31.85 to 31.95	18
1 1/4" (40mm)	39.75 to 39.95	20
1 1/2" (50mm)	49.75 to 49.95	23
2" (63mm)	62.65 to 62.95	27



The peeling length l corresponds to the length of the peeling blades.

For pipes of diameter d = 16 mm, chamfer about 2 mm of the pipe end at an angle of 15°. Prepare about 15 mm of the pipe end with a scraper. Mark off the jointing length of 13 mm on the pipe.

Thoroughly clean the fitting socket with absorbent paper and cleaning fluid (e. g. Tangit cleaner). Use fresh paper each time.

Fusion Joining Procedure

Heating

Quickly push first the fitting onto the heating spigot to the correct depth and then the pipe into the heating bush axially, without twisting, and hold firmly. The heating times in the table below are measured from this point on.

Fusion joints should not be used for pipes whose walls are thinner than those listed in the table.

Heating times and minimum wall thicknesses for socket fusion joints					
Pipe Outside Diameter (mm)	**Minimum Pipe Wall Thickness (mm)**	**Heating Time (sec)**	**Change (Max. Time) (sec)**	**Cooling Fixed (sec)**	**Cooling Total (min)**
3/8" (16mm)	1.5	4	4	6	2
1/2" (20mm)	1.9	6	4	6	2
3/4" (25mm)	1.9	8	4	6	2
1" (32mm)	2.4	10	4	12	4
1 1/4" (40mm)	2.4	12	4	12	4
1 1/2" (50mm)	3.0	18	4	12	4
2" (63mm)	3.0	20	6	18	6

The temperature and heating time must be strictly observed

Jointing (by hand)

Pull the fitting and pipe from the heating tools with a snap off action as soon as the heating period has elapsed.

Paying attention to the alignment marks, immediately push them together axially without twisting. Hold them together for the same duration as the heating period.

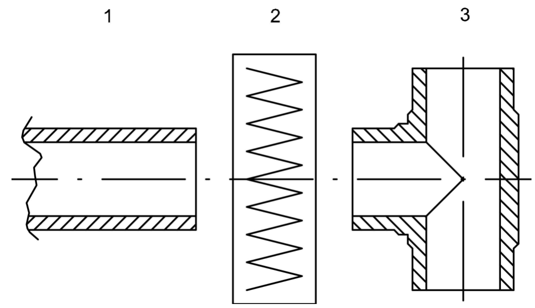
Pressure testing

All fusion joints must be allowed to cool completely before pressure testing, i.e. as a rule wait about an hour after the last joint has been completed.

Infrared (IR Plus®) Fusion

Infrared (IR) Fusion Joining Method

In infrared (IR) fusion joining the fusion areas of the components being joined (pipes, fittings, valves) are heated to fusion temperature without contact to the heating element and joined by means of mechanical pressure without using additional materials.



The Principle of Fusion Joining

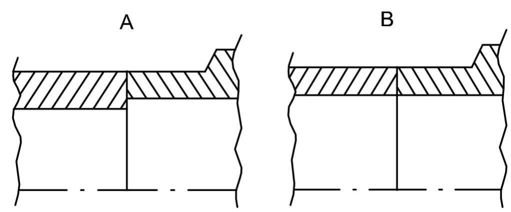
1 Pipe
2 Heating element
3 Fitting

The resulting fusion joints are homogeneous and display the following characteristics:

- Non-contact heating of the joining components eliminates the risk of contamination and inhomogeneities;
- Smaller joining beads due to adjustment of joining pressure path prior to the fusion process itself, i.e. elimination of the equalization process
- Adjustment of the joining pressure path also ensures excellent reproducibility of the fusion joints
- Low-stress fusion joints due to very uniform heating by means of IR radiator

General Requirements

The basic rule is that only similar materials can be fusion joined. For the best results only components which have a melt flow index in the range from $0.6x10^{-3}$lb/10min to $3.7x10^{-3}$lb/10min should be fusion joined. The components to be joined must have the same wall thicknesses in the fusion area. Maximum permissible wall displacement: 10%.



Only same wall thicknesses in the fusion area

A incorrect

B correct

IR fusion joining must only be performed by personnel trained in the use of this method. Training is provided world-wide by qualified GF IR Plus® welding instructors.

Tools Required

Infrared fusion joining requires a special joining machine in addition to the tools normally used for plastic pipe work construction (pipe cutters, etc.).

GF Supplies Three Types of IR Plus® Fusion Joining Machines

IR 63 Plus® for fusion 1/2" to 2"

IR 110 Plus® for fusion 1/2" to 4"

IR 225/315 Plus® for fusion 2" to 8"

General Conditions

Protect the area of the fusion joint from adverse weather conditions, such as rain, snow or wind. The permitted temperature range for IR Plus® fusion joining between 41°F (5°C) and 104°F (40°C). Outside this range, suitable action must be taken to ensure that these conditions are maintained. It must also be ensured that the components being joined are in this temperature range.

Preparing the Fusion Joint and Operating the IR Fusion Joining Machine

In principle, IR fusion joining machines do not require any special preparation, but it should be ensured that the components being joined are clean. Operation of the IR machines is defined exactly in the operating instructions, but we strongly recommend attending a 1-day training course to become a qualified IR welder.

Properties and Characteristics of IR Fusion Joints

Non-Contact Heating

The components being joined are heated uniformly and without contact to the ideal fusion temperature by infrared radiation.

A defined gap between the heating element and the end faces minimizes the risk of contamination of the joining surface. Contamination of the heating element by plastic particles is thus also eliminated.

Reduced Bead Formation

The fusion bead produced during joining is considerably reduced without any loss of quality. Bead forming equalization is eliminated by non-contact softening of the end faces. The minimal, defined bead is only formed during the joining process. The fusion area thus has improved flow dynamics, low clearance volume, and greater throughput area.

Reproducible Joining Processes

The joining path controls the joining pressure and thus the fusion process. The high reproducibility of the joints is assured by the clearly defined and controlled process sequence.

Clear, Simple Operator Guidance

Clear, unambiguous operator guidance via the liquid crystal display leads the user interactively through the fusion process in logical operating steps.

Welding Report/Traceability

The welding parameters for the relevant welding operations can be read out directly via various interfaces on the machine. It is possible to print these out on paper (commercially available printers), on labels or to employ electronic data output (PCMCIA card).

This automatically provides an accurate record with all essential fusion parameters for each individual fusion joint, as required.

Bead and Crevice Free (BCF® Plus) Fusion

Bead and Crevice Free (BCF® Plus) Fusion Joining Method

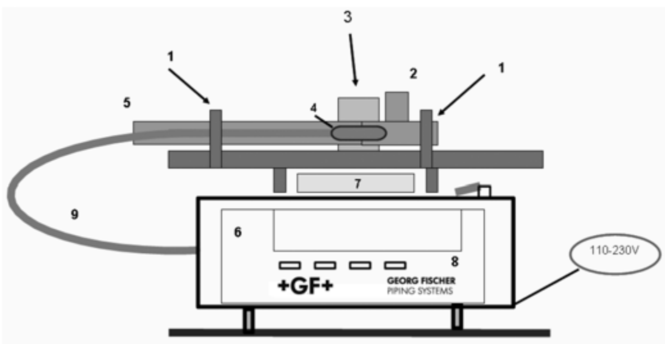
The fusion jointing process consists in transmitting precisely defined thermal energy to the pipe and fitting ends being joined by means of half-shell heating elements.

At the same time an elastic, pressurized bladder supports the inside surface of the fusion zone in order to prevent the formation of an internal fusion bead.

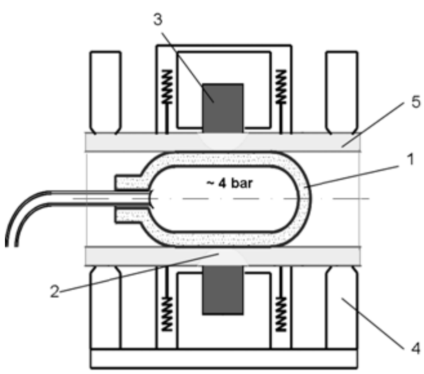
Holding the melted thermoplastic under controlled pressure ensures ideal, homogeneous fusion of the plastic components.

Fully automatic process control of the fusion jointing process with a fusion jointing machine developed in-house by GF permits very simple handling and reproducible fusion quality.

The Principle of Fusion Joining



1. Pipe Clamping Element
2. Fitting
3. Heating element with fitting - clamping device
4. Pressurized Bladder
5. Pipe
6. Compressor for Bladder
7. Cooling Air Blower
8. Control Panel
9. Compressed Air Supply



1. Pressurized Bladder
2. Welding Zone
3. Heating Element
4. Clamping Position
5. Pipe/Fitting

General Requirements

SYGEF® fittings and SYGEF® pipes are suitable for working pressures up to 232 psi (16 bar) at 68°F (20°C) (water). SYGEF® diaphragm valves are designed for a maximum working pressure of 150 psi (10 bar) at 68°F (20°C) (water). Refer to the chapter on pressure/temperature diagrams for details of permissible working pressures.

Tools required

BCF® jointing requires the Georg Fischer BCF® jointing machine in addition to the tools normally used for plastic pipework construction (pipe cutters, etc.).

Preparing the fusion joint and operating the BCF® Plus fusion jointing machine

In principle, BCF® Plus fusion jointing machines do not require any special preparation, other than to ensure that all components being joined are clean.

Operation of the BCF® Plus machines is defined exactly in the operating instructions, but we strongly recommend attending a 1-day training course to become a qualified BCF® welder.

Properties and characteristics of BCF® Plus fusion joints

Welding free from beads and crevices

The result of the jointing process is a surface similar to the actual pipeline components, free from beads or crevices. There are therefore no dead spaces, the surface roughness lies in the range Ra 9.8µin (0.25µm).

Reproducible jointing processes

The high reproducibility of the joints is assured by the clearly defined and controlled process sequence.

Clear, simple operator guidance

Clear, unambiguous operator guidance via the liquid crystal display leads the user interactively through the fusion process in logical operating steps.

Welding report/traceability

The welding parameters for the relevant welding operations can be read out directly via various interfaces on the machine. It is possible to print these out on paper (commercially available printers), on labels or to employ electronic data output (PCMCIA card).

This automatically provides an accurate record with all essential fusion parameters for each individual fusion joint.t

Validated Welding Process

Fusion Training and Certification

SYGEF® Plus HP (PVDF) piping installation shall only be performed by factory trained and certified installers in accordance with the manufacturer's written procedures. Each installer shall complete the manufacturers Certification Course including written test examinations and submittal of fusion test welds to the manufacturer for weld evaluation. All PVDF pipe, valves and fittings shall be properly prepared in accordance with high purity standards and the manufacturer's written instructions. Each certified welder shall display at all times a permanent certification card showing name, type of fusion machine, certification number and date of certification. Installation practices, including support spacing and expansion considerations, shall be in compliance with the manufacturer's certification course and written recommendations.

Fusion Equipment

All SYGEF® Plus HP (PVDF) Infrared Fusion Components shall be joined using the IR-63 Plus®,IR-110 Plus® or the IR-225 Plus® Infrared Fusion Machine. The infrared fusion machines shall utilize overlap distance measurement as a precise means of developing joining pressure. The joining equipment shall control the fusion process through an integrated software program which automatically compensates for ambient temperature variations and limits operator dependency. The fusion process shall produce repeatable weld profiles that can be visually inspected according to a specified Weld Inspection Program (see 2.8 Weld Inspection part A).

For ease of installation, all fusion equipment shall permit the use of remote or in-place fusion welding of all components up to 2" (63mm) diameter.

Printouts or electronic storage using a PCMCIA card for weld history and fusion parameters shall be made (and retained) for every weld. Printouts are accessible through a standard parallel port interface or PCMCIA card on the IR Plus Fusion machine.

Joining Times Using the IR Plus Fusion Equipment: The fusion times to complete an IR Plus weld shall be based on ambient temperature conditions which reduces the overall welding process by up to 50% compared to standard IR butt fusion. Typical fusion times shall be as follows:

Typical Fusion Times

Size (mm)	Size (inch)	Typical Fusion Time (sec)
1/2" (20mm)	1/2	108
3/4" (25mm)	3/4	108
1" (32mm)	1	152
1 1/4" (40mm)	1 1/4	152
1 1/2" (50mm)	1 1/2	203
2" (63mm)	2	149
2 1/2"(75mm)	2 1/2	187
3" (90mm)	3	214
4" (110mm)	4	254
6" (160mm)	6	263
8" (200mm)	8	294
8" (225mm)	9	330
10"(250mm)	10	754
12" (315mm)	12	890
14"(355mm)	14	Consult Factory
16"(400mm)	16	Consult Factory
18" (450mm)	18	Consult Factory

Weld Inspection

Georg Fischer shall provide a written Weld Inspection Program to the Quality Inspector or System Owner that specifies minimum guidelines for IR weld acceptance. Inspection of infrared butt fusion welds shall reveal uniform double fusion beads of minimal size and proper alignment of component parts having a maximum displacement relating to 10% of the pipe wall thickness. All properly made IR fusion welds should be uniform in color with a smooth and consistent appearance indicating proper fusion temperature, heating time and joining pressure. At a minimum the following requirements shall be met:

- Two complete weld beads for the full 360° circumference
- No contamination within the fusion zone
- A maximum of 10% component misalignment
- The "k" value ("k" defined as the height as measured at the center of weld bead compared to pipe wall) shall be ≥ 0. For further criteria refer to manufacturer's Weld Inspection Program (WIP).-

Mechanical Connections

Mechanical Joining of Piping Systems

Flange Connections	Flange adapters for butt fusion Coated Metal Flanges Backing Rings
Unions	Plastics-oriented connections between same plastics Transitions to other plastics Seal: O-ring
Threaded Fittings	Plastic fittings with reinforcement ring and tapered Female NPT threads.

Threaded Connections

The Following Different Types of Threads Are Used

Designation of the thread	According to standard	Typical use	Description
G (Buttress Threads)	ISO 228	Unions	Parallel internal or external pipe thread, where pressure-tight joints are not made on the threads
NPT = National (American Standard) Pipe Taper	ASTM F1498	Transition and threaded fittings	Taper internal or external pipe thread for plastic pipes and fittings, where pressure-tight joints are made on the threads

Flanged Connections

Creating Flange Joints

When making a flange connection, the following points have to be taken into consideration:

There is a general difference between the connection of plastic pipes and so-called adapter joints, which represent the transition from a plastic pipe to a metal pipe or a metal valve. Seals and flanges should be selected accordingly.

Flanges with sufficient thermal and mechanical stability should be used. GF flange types fulfil these requirements.

A robust and effective seal can only be achieved if sufficient compressive forces are transmitted to the flange stub end via the backup ring. These compressive forces must be of sufficient magnitude to overcome fluctuating hydrostatic and temperature generated forces encountered during the lifetime of the joint. In assembling the stub ends, gasket and backup rings it is extremely important to ensure cleanliness and true alignment of all mating surfaces. The correct bolt tightening procedure must also be followed and allowance made for the stress relaxation characteristics of the plastic stub ends.

Alignment

1. Full parallel contact of the sealing faces is essential.
2. The backup ring must contact the stub end evenly around the circumference.
3. Misalignment can lead to excessive and damaging stresses in either the stub

Creating Flange Joints

When to Use a Flange?

Flanges may be used when:

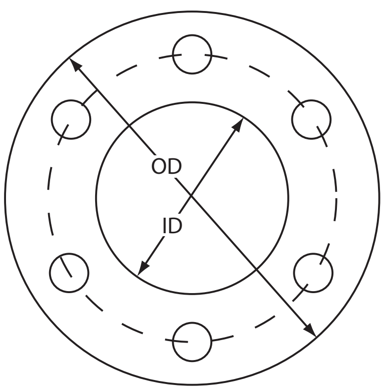
- The piping system may need to be dismantled
- The installation is temporary or mobile
- Transitioning between dissimilar materials that can not be bonded together

Vinyl Flanges

Visually inspect flanges for cracks, deformities or other obstructions on the sealing surfaces.

Gasket

A rubber gasket must be used between the flange faces in order to ensure a good seal. GF recommends a 0.125" thick, full-face gasket with Shore A scale hardness of 70±5, and the bolt torque values **(Table 9)** are based on this specification. For other hardness requirements, contact GF Technical Services. Select the gasket material based on the chemical resistance requirements of your system. A full-face gasket should cover the entire flange-to-flange interface without extending into the flow path.



Size (in)	O.D. (in)	I.D. (in)
1/2" (20mm)	3.50	0.59
3/4" (25mm)	3.86	0.79
1" (32mm)	4.25	1.02
1 1/4" (40mm)	4.61	1.34
1 1/2" (50mm)	5.00	1.69
2" (63mm)	5.98	2.20
2 1/2"(75mm)	7.01	2.60
3"(90mm)	7.48	3.07
4" (110mm)	9.02	3.94

Size (in)	O.D. (in)	I.D. (in)
6" (160mm)	10.98	5.94
8" (200mm)	13.50	8.15
8" (225mm)	13.50	8.15
10" (250mm)	16.00	9.84
12" (315mm)	19.00	11.81
14" (355mm)	21.00	12.87
16" (400mm)	23.50	15.39
18" (450mm)	27.00	16.77

Fasteners

It is critical to avoid excessive compression stress on a plastic flange. Therefore, only low-friction fastener materials should be used. Low-friction materials allow torque to be applied easily and gradually, ensuring that the flange is not subjected to sudden, uneven stress during installation, which can lead to cracking.

Either the bolt or the nut, and preferably both, should be zinc-plated to ensure minimal friction. If using stainless steel bolt and nut, lubricant must be used to prevent high friction and seizing. In summary, the following fastener combinations are acceptable:

- zinc-on-zinc, with or without lube
- zinc-on-stainless-steel, with or without lube
- stainless-on-stainless, with lube only

Cadmium-plated fasteners, while becoming more difficult to obtain due to environmental concerns, are also acceptable with or without lubrication. Galvanized and carbon-steel fasteners are not recommended. Use a copper-graphite anti seize lubricant to ensure smooth engagement and the ability to disassemble and reassemble the system easily. Bolts must be long enough that two complete threads are exposed when the nut is tightened by hand. Using a longer bolt does not compromise the integrity of the flange connection, although it wastes material and may make tightening more difficult due to interference with nearby system components.

Fastener Specifications - SYGEF® PVDF

Flange Size (in)	No. of Bolts	Length[1] (in)	Bolt Size (in) and Type	Washer Size (in) and Type[2]
1/2" (20mm)	4	3.25	1/2" SAE GRD 5	1/2" SAE
3/4" (25mm)	4	3.50	1/2" SAE GRD 5	1/2" SAE
1" (32mm)	4	3.50	1/2" SAE GRD 5	1/2" SAE
1 1/4" (40mm)	4	3.75	1/2" SAE GRD 5	1/2" SAE
1 1/2"(50mm)	4	4.00	1/2" SAE GRD 5	1/2" SAE
2" (63mm)	4	4.50	1/2" SAE GRD 5	1/2" SAE
2 1/2" (75mm)	4	5.00	5/8" SAE GRD 5	5/8" SAE
3" (90mm)	4	5.00	5/8" SAE GRD 5	5/8" SAE
4" (110mm)	8	5.00	5/8" SAE GRD 5	5/8" SAE
6" (160mm)	8	6.50	3/4" SAE GRD 5	3/4" SAE
8" (200mm)	8	7.00	3/4" SAE GRD 5	3/4" SAE
8" (225mm)	8	7.00	3/4" SAE GRD 5	3/4" SAE
10" (250mm)	12	7.50	7/8" SAE GRD 5	7/8" SAE
12" (315mm)	12	8.00	7/8" SAE GRD 5	7/8" SAE
14" (355mm)	12	8.00	1" SAE GRD 5	1" SAE
16" (400mm)	16	9.00	1" SAE GRD 5	1" SAE
18" (450mm)	16	10.00	1 1/8" SAE GRD 5	1 1/8" SAE

[1] Suggested bolt length for flange-to-flange connection with 0.125" thick gasket. Adjust bolt length as required for other types of connections.

[2] Minimum spec. Use of a stronger or thicker washer is always acceptable as long as published torque limits are observed.

[3] Also known as Type A Plain Washers, Narrow Series.

[4] ASTM F436 required for larger sizes to prevent warping at high torque.

A washer must be used under each bolt head and nut. The purpose of the washer is to distribute pressure over a wider area, reducing the compression stress under the bolt head and nut. Failure to use washers voids the GF warranty.

Torque Wrench

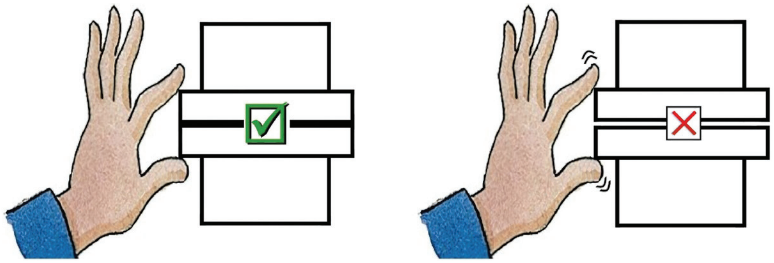
Compared to metals, plastics are relatively flexible and deform slightly under stress. Therefore, not only must bolt torque be controlled in order to avoid cracking the flange, but continuing to tighten the bolts beyond the recommended torque levels may actually make the seal worse, not better.

Because bolt torque is critical to the proper function of a plastic flange, a current, calibrated torque wrench accurate to within ±1 ft.lb. must be used when installing plastic flanges.

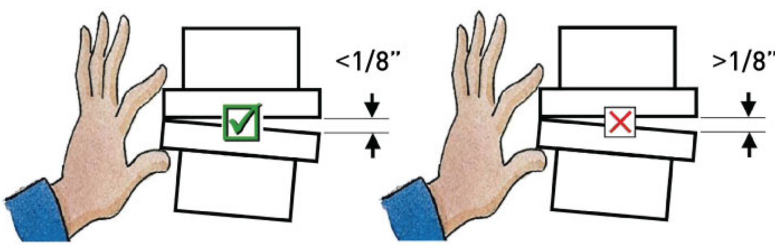
Experienced installers may be tempted to forgo the use of a torque wrench, relying instead on "feel." GF does not endorse this practice. Job-site studies have shown that experienced installers are only slightly better than new trainees at estimating bolt torque by feel. A torque wrench is always recommended.

Checking System Alignment

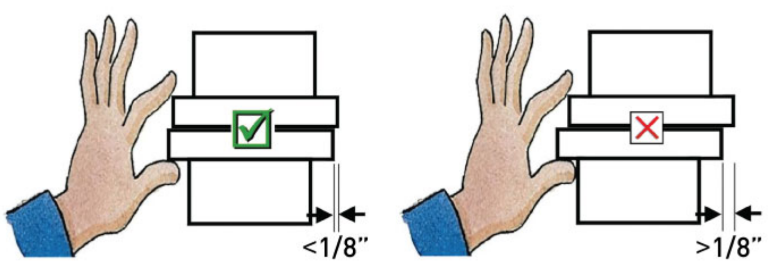
Before assembling the flange, be sure that the two parts of the system being joined are properly aligned. GF has developed a "pinch test" that allows the installer to assess system alignment quickly and easily with minimal tools. First check the gap between the flange faces by pinching the two mating components toward each other with one hand as shown below. If the faces can be made to touch, then the gap between them is acceptable.



Next check the angle between the flange faces. If the faces are completely flush when pinched together, as shown above, then the alignment is perfect, and you may continue installation. Otherwise, pinch the faces together so that one side is touching, then measure the gap between the faces on the opposite side. The gap should be no more than 1/8".



To assess high-low misalignment, pull the flange faces flush together. If the faces are concentric within 1/8", then the high-low misalignment is acceptable



If the gap between the mating components can not be closed by pinching them with one hand, or if the angle or high-low misalignment between them is too large, then using the bolts to force the components together will result in excessive stress and possible failure during or after installation. In this case, inspect the system to find the greatest source of misalignment and refit the system with proper alignment before bolting.

Tightening the Bolts

Tightening one bolt to the maximum recommended torque while other bolts are only hand-tight, or tightening bolts in the wrong order, produces uneven stresses that may result in poor sealing. To ensure even distribution of stresses in the fully-installed flange, tighten the bolts in a star pattern as described in ANSI B16.5.

The torque required on each bolt in order to achieve the best seal with minimal mechanical stress has been carefully studied in laboratory and field installations, and is given in **Table 9**.

To ensure even distribution of stresses and a uniform seal, tighten the bolts to the first torque value in the sequence, using a star pattern, then repeat the star pattern while tightening to the next torque value, and so on up to the maximum torque value.

All plastics deform slightly under stress. A final tightening after 24 hours is recommended, when practical, to ensure that any bolts that have loosened due to relaxation of the polymer are fully engaged.

If a flange leaks when pressure-tested, retighten the bolts to the full recommended torque and retest. Do not exceed the recommended torque before consulting an engineer or GF representative.

Table 9
Multiple Pass Bolt Torque

Size	Size	Max.	Torque Sequence (ft-lb, lubed*)				Torque Sequence (ft-lb, unlubed**)			
(in)	(mm)	Torque	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1/2"	20mm	22	5	—	—	—	5	10	22	—
3/4"	25mm	22	5	—	—	—	5	10	22	—
1"	32mm	22	5	—	—	—	5	10	22	—
1 1/4"	40mm	22	5	—	—	—	5	10	22	—
1 1/2"	50mm	22	5	—	—	—	5	10	22	—
2"	63mm	22	5	—	—	—	5	10	22	—
2 1/2"	75mm	30	5	12	30	—	15	20	30	—
3"	90mm	30	5	12	30	—	15	20	30	—
4"	110mm	30	10	15	30	—	15	25	30	—
6"	160mm	44	12	24	44	—	20	32	44	—
8"	200/225mm	58	15	35	58	—	30	40	50	58
10"	250mm	58	25	50	58	—	20	40	50	58
12"	315mm	75	30	60	75	—	20	50	65	75
14"	355mm	140	46	92	126	140	35	70	105	140
16"	400mm	140	46	92	126	140	35	70	105	140
18"	450mm	140	46	92	126	140	35	70	105	140

* Assumes the use of SS, zinc- or cadmium-plated bolt and/or nut along with copper-graphite anti seize lubricant brushed directly onto the bolt threads.

** Assumes the use of zinc- or cadmium-plated bolt, nut, or both. Never use unlubricated, uncoated bolts and nuts with plastic flanges, as high friction and seizing lead to unpredictable torque and a high incidence of cracking and poor sealing.

Note that the torques listed in **Table 9** are for flange-to-flange connections in which the full faces of the flanges are in contact. For other types of connections, such as between a flange and a butterfly valve, where the full face of the flange is not in contact with the mating component, less torque will be required. Do not apply the maximum listed torque to the bolts in such connections, which may cause deformation or cracking, since the flange is not fully supported by the mating component. Instead, start with approximately two-thirds of the listed maximum torque and increase as necessary to make the system leak-free after pressure testing.

Documentation

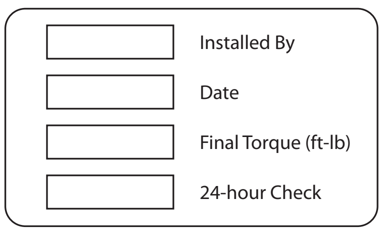
Keep Instructions Available

Provide a copy of these instructions to every installer on the job site prior to beginning installation. Installers who have worked primarily with metal flanges often make critical mistakes when installing plastic flanges. Even experienced plastic installers will benefit from a quick review of good installation practices before starting a new job.

Installation Tags

Best practices include tagging each flange with

- Installer's initials
- Installation date
- Final torque value (e.g., "29.2-31.5")
- Confirmation of 24-hour torque check ("y" or "n")



This information can be recorded on pre-printed stickers, as shown below, and placed on each flange immediately after installation.

Experience has shown that installation tags speed up the process of resolving system leaks and product failures, improve communication between the contractor and distributor or manufacturer, highlight training opportunities, and promote worker diligence.

Creating Union Joints

Introduction

Because unions and ball valves have similar, threaded nut connectors, these instructions have been written with both of these components in mind. GF unions and ball valves are designed to provide many years of service when installed properly.

As with any piping system component, unions and valves have particular considerations that must be kept in mind during installation in order to ensure best performance. Even experienced installers will benefit from reviewing these instructions before each installation.

Valve Support

Valves must be well-supported. An unsupported or insufficiently-supported valve body will twist when opened and closed, subjecting the union connection to torque stress that may cause cracking or distortion and subsequent leakage.

System Alignment

The major contributor to union nut failures is misalignment. Uneven compression of the o-ring will cause leaks to occur. Union nuts can be damaged by the stress of holding a misaligned system together.

Sealing Mechanism

GF union connections use an o-ring as the sealing mechanism which is highly effective under relatively low tightening force.

Dirt and Debris

An often overlooked issue is the presence of dirt and debris on the o-ring or sealing surface. This will prevent proper o-ring sealing; if it is present on the nut or body threads, it will clog the threads and prevent proper tightening.

Installation

Understand and carefully follow these installation steps in order to ensure a seal that is sufficient to guard against leaks while avoiding excessive forces that can damage the union nut.

End Connectors

Always remove the union nut and end connectors from the ball valve for installation. Make sure that you slide the union nut onto the pipe, with the threads facing the proper direction, BEFORE installing the end connector.

O-Ring Placement

Once the cement has cured, ensure that the o-ring is securely seated in its groove. The o-ring should rest securely in place without adhesive or other aids.

Never use any foreign substance or object to hold the o-ring in place.

Union Connection

There should be no gap between the mating components, so that the threaded nut serves only to compress the o-ring, thus creating the seal. However, a small gap (less than 1/8") between the mating components is acceptable.

Never use the union nuts to draw together any gaps between the mating faces of the components or to correct any system misalignment.

Hand-Tightening (all sizes) (see Table 10)

The next step is to hand-tighten the union nut. With the o-ring in place, engage the nut with its mating threads and turn clockwise with one hand. Continue turning with moderate force until the nut no longer turns.

Be careful to use reasonable force when tightening the nut. Your grip should be firm but not aggressive. The nut should turn easily until it bottoms out and brings the mating faces into direct contact.

It is recommended that you place an indexing mark with a permanent marker on the union nut and body to identify the hand tight position.

Optional: Further Tightening (2") (see Table 10)

Based on experience, or system requirements, the installer may choose to turn the nut an additional 1/8 turn (approximately 45°) in order to ensure a better seal before hydrostatically pressure testing the system. To do this, use a strap wrench to turn the nut 1/8 turn past the index mark applied after assembly.

Do not exceed 1/8 turn past the index mark.

Do not use any metallic tools. (Tool marks on the union nut will void manufacturer's warranty.)

At this point, the system should be hydrostatically pressure tested before turning the union nut any farther.

Table 10
Tightening Guide for Union and Ball Valve Nuts

Nominal Size (inch)	Initial	Additional Pre-Test	Additional Post-Test
½	Hand-Tight	None	1/8 Turn (max)
¾	Hand-Tight	None	1/8 Turn (max)
1	Hand-Tight	None	1/8 Turn (max)
1½	Hand-Tight	None	1/8 Turn (max)
2	Hand-Tight	1/8 Turn (max)	1/8 Turn (max)

Post-Test Tightening (Sizes 3/8" to 1½" only) (see Table 10)

It is highly unlikely that any union nut connection; when tightened as instructed above, will leak under normal operating conditions.

In the unlikely event that a leak occurs, the union nut at the leaking joint may be tightened an additional 1/8 turn, as described above. The system should then be re-tested. If the joint still leaks after post-test tightening, do not continue to tighten the nut at the leaking joint. Disassemble the leaking joint, re-check system alignment, and check for obstructions in the sealing area. If the cause of a leak can not be determined, or if you suspect that the union or valve is defective, contact your GF representative at (800) 854-4090 for further instructions.

Quality Check After Assembly

To check if the union connections are installed in a stress-free manner, GF recommends that a random check of alignment be done by removing the nut on selected union connection one at a time. A properly installed system will not have any movement of the piping as the nut is loosened. If any springing action is noticed, steps should be taken to remove the stress prior to re-installing the union nut.

Documentation

Keep Instructions Available

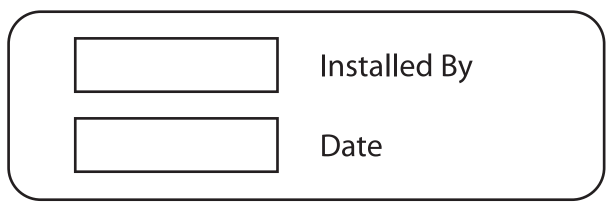
Provide a copy of these instructions to every installer on the job site prior to beginning installation.

Installation Tags

Best practices include tagging each union with:

- Installer's initials
- Installation date

This information can be recorded on pre-printed stickers, as shown below, and placed on each union nut immediately after installation.



Experience has shown that installation tags speed up the process of resolving system leaks and product failures, improve communication between the contractor and distributor or manufacturer, highlight training opportunities, and promote worker diligence. See the GF vinyl technical manual for information on guides, support spacing, and allowance for thermal expansion.

Creating Threaded Joints

Introduction

NPT threaded connections are not recommended for high pressure systems or those greater than two inches. They also should be avoided in systems where leaks would be dangerous or costly.

When properly installed, threaded connections offer the benefit of an easy and inexpensive transition to metal systems. They can also be used for joining plastic where the installation is expected to be modified or moved later.

Design Considerations

Due to the difference in stiffness between plastic and metal, a metal male-to-plastic female joint must be installed with care and should be avoided if possible. Only molded or machined adapters may be threaded. Threading reduces the rated pressure of the pipe by one-half.

Preparation

Thread Sealant

A thread sealant (or "pipe dope") approved for use with plastic or PTFE ("Teflon") tape must be used to seal threads.

Use a thin, even coat of sealant.

PTFE tape must be installed in a clockwise direction, starting at the bottom of the thread and overlapping each pass. GF recommends no more than 3 wraps.

Making the Connection

Start the threaded connection carefully by hand to avoid cross threading or damaging threads. Turn until hand tight. Mark the location with a marker. With a strap wrench on the plastic part, turn an additional half turn. If leakage occurs during pressure testing, consult the chart for next steps.

Threaded Connection Guide

Connection Type	Next Step
Plastic to Plastic	Tighten up to 1/2 turn
Plastic Male to Metal Female	Tighten up to 1/2 turn
Metal Male to Plastic Female	Consult Factory

Alignment

Threaded connections are susceptible to fracture or leaking due to misalignment. Pipe should be installed without bending.

Pressure Testing

Introduction

A lot of international and national standards and guidelines are available for leak and pressure tests. Therefore often it is not easy to find the applicable test procedure or for example the test pressure.

The purpose of a pressure test is to:

- Ensure the resistance to pressure of the pipeline and
- Show the leak tightness against the test media.

Usually the pressure test is done as a water pressure test and only in exceptional cases (with consideration to special safety precautions) as a gas pressure test with air or nitrogen.

The following comparison should point out the difference between water and air as a test medium:

- Water is an incompressible medium, which means, setting for example a 3.2ft (1m) PVDF pipe 6" (160mm) under a pressure of 45 psi (3 bar) results in an energy of ca. 1 Joule.
- In contrast air is a compressible medium; the same pipe has with 45 psi (3 bar) pressure an energy of already 5000 Joule.
- If there were a failure during the pressure test, the waterfilled pipe would fly 1" high, the airfilled pipe 360ft! And this with a test pressure of only 45psi (3 bar).

Fractural Behavior of Thermoplastics

In case of failures thermoplastic materials show different behaviors. PE and PB (to a lesser degree ABS) have a ductile behavior, that means brittle fracture cannot occur.

Nevertheless, the following safety precautions must be taken into consideration during the internal pressure test. As mentioned before the pressure test is the first loading placed on the pipeline and uncover any existing processing faults (e.g. insufficient welding).

Remark: Gas leak tightness cannot be demonstrated by =a water pressure test, also not with increased test pressure!

Overview of the different testing methods

Testing Method	**Internal Pressure Test**			**Leak Test**	
Medium	Water	Gas/Air*	Compressed Air*	Gas/Air	Gas/Air
Behavior	Incompressible	Compressible	Compressible	Compressible	Compressible
Test Pressure	1.5 x Operating (up to system max.)	Operating (up to system max., but not to exceed 150psi)		7 psi (0.5 bar)	22 psi (1.5 bar)
Safety Hazard	Minor	High	High	Minor	Moderate
Material	All Plastics	ABS	PB, PE	All Plastics	ABS
Informative Value	High: Proof of resistance to pressure including tightness against test medium	High: Proof of resistance to pressure including tightness against test medium	High: Proof of resistance to pressure including tightness against test medium	Minor	Moderate

*** Please consider the applicable safety precautions**

Internal pressure test with water or a similar incompressible test fluid

General

The internal pressure test is done when installation work has been completed and necessitates an operational pipeline or operational test sections. The test pressure load should furnish experimental proof of operational safety. The test pressure is not based on the working pressure, but rather on the internal pressure load capacity, derived from the pipe wall thickness.

Test pressures are therefore determined in relation to SDR and the pipe wall temperature. The 100-h value from the long-term behavior diagram is used for the test clamping.

Test Parameters

The following table indicates recommended methods of testing the internal pressure.

Object	Pre-Test	Main Test
Test pressure P (depends on the pipe wall temperature or the permissible test pressure of the built-in components, see clause Determining the test pressure)	≤ P	≤ 0.85 x P
Test duration (depends on the length of the pipeline, respectively the sections)	L ≤ 325ft : 3 h 325ft < L ≤ 1640ft : 6 h	L ≤ 325ft : 3 h 325ft < L ≤ 1640ft : 6 h
Checks during the testing (test pressure and temperature progression should be recorded)	At least 3 checks, distributed over the test duration **with** restoring the test pressure	At least 2 checks, distributed over the test duration **without** restoring the test pressure

Pre-test

The pre-test serves to prepare the piping system for the actual test (main test). In the course of pre-testing, a tension-expansion equilibrium in relation to an increase in volume will develop in the piping system. A material-related drop in pressure will occur which will require repeated pumping to restore the test pressure and also frequently a re-tightening of the flange connection screws.

The guidelines for an expansion-related pressure decrease in pipes are:

Material	Pressure Drop
PVC	7.2 psi/h (0.5 bar/h)
CPVC	7.2 psi/h (0.5 bar/h)
ABS	8.7 psi/h (0.6 bar/h)
PP	11.6 psi/h (0.8 bar/h)
PE	17.4 psi/h (1.2 bar/h)
PB	20.3 psi/h (1.4 bar/h)
PVDF	11.6 psi/h (0.8 bar/h)

Main test

In the context of the main test, a much smaller drop in pressure can be expected at constant pipe wall temperatures so that it is not necessary to pump again. The checks can focus primarily on leak detection at the flange joints and any position changes of the pipe.

Observe if using compensators

If the pipeline to be tested contains compensators, this has an influence on the expected axial forces of the pipeline. Because the test pressure is higher than the working pressure, the axial forces on the fixed points become higher. This has to be taken into account when designing the fixed points.

Observe if using valves

When using a valve at the end of a pipeline (end or final valve), the valve and the pipe end should be closed by a dummy flange or cap. This prevents inadvertent opening of the valve or any pollution of the inside of the valve.

Filling the pipeline

Before starting with the internal pressure test, the following points must be checked:

- Was installation done according to the available plans?
- All pressure relief devices and flap traps mounted in the flow direction?
- All end valves shut?
- Valves in front of other devices are shut to protect against pressure.
- Visual inspection of all joints, pumps, measurement devices and tanks.
- Has the waiting period after the last fusion / cementing been observed?

Now the pipeline can be filled from the geodetic lowest point. Special attention should be given to the air vent. If possible, vents should be provided at all the high points of the pipeline and these should be open when filling the system. Flushing velocity should be at least 3ft/sec.

Reference values for the filling volume are given in the table below.

Adequate time should be allowed between filling and testing the pipeline, so that the air contained in the piping system can escape via the vents: ca. 6 - 12 h, depending on the nominal diameter.

	Pipe Size (d) Diameter	
Test Pressure (%)	**up to 110mm**	**160 to 450**
10	< 3 min	3 - 7 min
20	< 6 min	6 - 20 min
30	< 9 min	9 - 30 min
40	< 12 min	12 - 40 min
50	< 15 min	15 - 50 min
60	< 17 min	17 - 63 min
70	< 21 min	21 - 77 min
80	< 24 min	24 - 93 min
90	< 28 min	28 - 105 min
100	< 30 min	

Pipe Size	V (gpm)
≤ 3" (90mm)	2.3
4" (110mm)	4.8
6" (160mm)	11.0
8" (200/225mm)	24.0
10" (250mm)	32.0
12" (315mm)	48.0
14" (400mm) and Above	> 95.0

Max Test Pressure

	50°F (10°C)	68°F (20°C)	86°F (30°C)	104°F (40°C)	122°F (50°C)
SYGEF® PVDF (PN16)	300 psi	300 psi	275.5	246.5	217.0
SYGEF® PVDF (PN10)	191 psi	191 psi	174.0	159.9	140.0

Checks during testing

The following measurement values must be recorded consistently during testing:

- Internal pressure at the absolute low point of the pipeline
- Medium and ambient temperature
- Water volume input
- Water volume output
- Pressure drop rates

Internal pressure test with gas (compressible medium). Maximum test pressure should never exceed 7 psi (0.5 bar) max.

If it is not possible to do an internal pressure test with water (e.g. pipeline must be kept dry), a leak test can be carried out with slight overpressure. For safety reasons the test pressure must then be limited to maximum 7 psi (0.5 bar).

For the leak test all the joints should be sprayed with a foam-forming medium and subsequently checked. A soap solution, which can be removed simply with water after the test, is best.

Attention: Commercial leak detection sprays can cause stress cracks in plastics. Using these sprays remove any residues after testing.

Since the efficiency of this leak test is very restricted due to the low load, it should be used preferably for systems with working pressures under 7psi (0.5 bar).

Modifications and repairs

The following safety measures are to be observed when modifying or repairing piping systems:

- wear protective clothing
- drain the respective pipeline section completely
- rinse the pipe section
- protect against dripping
- clean and dry the joints

An important factor for the competent repair of piping systems is to have the work carried out by trained professionals.

Modifications and repair work may not weaken the piping system mechanically.

To ensure the operational safety of the piping system following a modificati or a repair, an interanl pressure test should be done.

Commissioning

When putting a pipeline into operation for the first time, besides the internal pressure test, temperature effects are also generally examined. Thermal stress, i.e. expansion, was not simulated during testing.

We recommend an initial inspection at the earliest 3 days, at the latest 7 days, after commissioning and recording the results.

The inspection checks should include:

- critical points in the system (visual inspection)
- flange joints, unions, valves (leak-proof)
- safety and leak detection equipment (condition, function)

Continuous inspection of the piping system should be done by operating personnel during their usual rounds according to the operating instructions.

Sterilization and Sanitization Methods

Autoclave Sterilization

PVDF piping components exhibit no changes upon repeated exposure to typical temperatures experienced in autoclave cycles; however, autoclaving is not recommended for PVDF valves due to dissimilar materials for construction of diaphragm and valve bonnets.

In-Line Steam

PVDF piping, fittings and valves exhibit thermal stability up to 284°F (140°C). Therefore, in-line steam sterilization, typically executed at temperatures of up to 273°F (134°C), can be performed without adverse affects, provided that the pipe is properly supported. PVDF offers better insulation than metal and has a significantly lower surface temperature.

Ozone Sanitization

PVDF can be sanitized using continuous ozone concentration levels of up to 0.2 ppm without adverse effects. Ozone is commonly removed using UV light at a wavelength of 1.0×10^{-5}in (254nm). The light sources can be safely installed in PVDF piping systems provided a 90° deflection is introduced by either a fully lined diaphragm valve or a 90° stainless steel elbow. Ozone does not require the purchase of additional cleaning agents; does not require rinsing of the system afterwards; and does not add unwanted substances in the water.

Hot Water Sanitization

PVDF is rated up to maximum operating temperatures of 284°F (140°C), it can be hot water sanitized which requires no additives or removal processes. This method of sanitization is typically used to maintain USP and WFI systems for the pharmaceutical industry. PVDF systems that are operated for long periods of time at temperatures above 140°F (60°C) will need to be properly supported at all horizontal and vertical lengths of the piping system.

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Australia
George Fischer Pty Ltd
Riverwood NSW 2210 Australia
Phone +61(0)2 9502 8000
australia.ps@georgfischer.com
www.georgefischer.com.au

Austria
Georg Fischer
Rohrleitungssysteme GmbH
3130 Herzogenburg
Phone +43(0)2782 856 43-0
austria.ps@georgfischer.com
www.georgfischer.at

Belgium / Luxembourg
Georg Fischer NV/SA
1070 Bruxelles/Brüssel
Phone +32(0)2 556 40 20
be.ps@georgfischer.com
www.georgfischer.be

Brazil
George Fischer Ltda
04795-100 São Paulo
Phone +55(0)11 5687 1311
br.ps@georgfischer.com

Canada
Georg Fischer Piping Systems Ltd
Brampton, ON L6T 4E3
Phone +(905) 792-8005
ca.ps@georgfischer.com
www.gfpiping.ca

China
Georg Fischer
Piping Systems Ltd Shanghai
Pudong, Shanghai 201319
Phone +86(0)21 58 13 33 33
china.ps@georgfischer.com
www.cn.piping.georgfischer.com

Denmark / Iceland
Georg Fischer A/S
2630 Taastrup
Phone +45 (0)70 22 19 75
info.dk.ps@georgfischer.com
www.georgfischer.dk

France
Georg Fischer SAS
95932 Roissy Charles de Gaulle Cedex
Phone +33(0)1 41 84 68 84
fr.ps@georgfischer.com
www.georgefischer.fr

Germany
Georg Fischer GmbH
73095 Albershausen
Phone +49(0)7161 302-0
info.de.ps@georgfischer.com
www.georgfischer.de

India
Georg Fischer Piping Systems Ltd
400 076 Mumbai
Phone +91 224007 2001
in.ps@georgfischer.com
www.georgfischer.in

Italy
Georg Fischer S.p.A.
20063 Cernusco S/N (MI)
Phone +3902 921 861
it.ps@georgfischer.com
www.georgfischer.it

Japan
Georg Fischer Ltd
556-0011 Osaka,
Phone +81(0)6 6635 2691
jp.ps@georgfischer.com
www.georgfischer.jp

Korea
Georg Fischer Piping Systems
Guro-3 dong, Guro-gu, Seoul, Korea
Phone +82(0)2 2081 1450
Fax +82(0)2 2081 1453
kor.ps@georgfischer.com

Malaysia
Georg Fischer (M) Sdn. Bhd.
40460 Shah Alam, Selangor
Phone +60 (0)3 5122 5585
conne.kong@georgfischer.com

Mexico
Georg Fischer S.A. de C.V.
Apodaca, Nuevo Leon
CP66636 Mexico
Phone +52 (81)1340 8586
Fax +52 (81)1522 8906

Middle East
George Fischer Piping Systems
Dubai, United Arab Emirates
Phone +971 4 289 49 60
info.export@georgfischer.com
www.export.georgfischer.com

Netherlands
Georg Fischer N.V.
8161 PA Epe
Phone +31(0)578 678 222
nl.ps@georgfischer.com
www.georgfischer.nl

Norway
Georg Fischer AS
1351 Rud
Phone +47(0)67 18 29 00
no.ps@georgfischer.com
www.georgfischer.no

Poland
Georg Fischer Sp. z o.o.
02-226 Warszawa
Phone +48(0)22 313 10 50
poland.ps@georgfischer.com
www.georgfischer.pl

Romania
Georg Fischer
Piping Systems Ltd
020257 Bucharest - Sector 2
Phone +40(0)21 230 53 80
ro.ps@georgfischer.com
www.export.georgfischer.com

Russia
Georg Fischer Piping Systems
Moscow 125047
Tel. +7 495 258 60 80
ru.ps@georgfischer.com
www.georgfischer.ru

Singapore
George Fischer Pte Ltd
528 872 Singapore
Phone +65(0)67 47 06 11
sgp.ps@georgfischer.com
www.georgefischer.com.sg

Spain / Portugal
Georg Fischer S.A.
28046 Madrid
Phone +34(0)91 781 98 90
es.ps@georgfischer.com
www.georgfischer.es

Sweden / Finland
Georg Fischer AB
12523 Älvsjö-Stockholm
Phone +46(0)8 506 775 00
info.se.ps@georgfischer.com
www.georgfischer.se

Switzerland
Georg Fischer
Rohrleitungssysteme (Schweiz) AG
8201 Schaffhausen
Phone +41(0)52 631 30 26
ch.ps@georgfischer.com
www.piping.georgfischer.ch

Taiwan
Georg Fischer Piping Systems
San Chung City, Taipei Hsien
Phone +886 2 8512 2822
Fax +886 2 8512 2823

United Kingdom / Ireland
George Fischer Sales Limited
Coventry, CV2 2ST
Phone +44(0)2476 535 535
uk.ps@georgfischer.com
www.georgefischer.co.uk

USA / Latin America / Caribbean
Georg Fischer LLC
Tustin, CA 92780-7258
Phone +1(714) 731 88 00
Toll Free 800 854 40 90
us.ps@georgfischer.com
www.gfpiping.com

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