FLANGES AND FLANGE ADAPTERS FOR POLYPROPYLENE (PP-R & PP-RCT) PIPING SYSTEMS

PPI TN-71

2024

Plastics Pipe Institute
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Foreword

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The purpose of this technical note is to provide information regarding flanges and flange adapters for polypropylene (PP) piping systems.

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This Technical Note, TN-71, was first issued in October 2024.

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FLANGES AND FLANGE ADAPTERS FOR POLYPROPYLENE (PP-R & PP-RCT) PIPING SYSTEMS

PREFACE

Polypropylene pressure pipes and fittings are often joined to each other by heat fusion methods known as butt fusion, socket fusion, or electrofusion. Flanged connections are used as transitions to pipes of other materials (e.g., steel), connections to flanged fittings and valves, or as end connections on fabricated pipe spools and assemblies.

Flanged joints prevent leakage by compressing a deformable gasket material into irregularities in a less deformable material to seal possible leak paths. The mating faces of flanged joints are the surface areas that need to be sealed. The deformation characteristics of the deformable material, including gasket hardness, compressive strength, and compression set, are the primary determinant of the amount of compression, expressed as force per unit area, or pressure, required to properly seal a flanged joint.

It is desirable to utilize common bolting patterns to facilitate connections to readily available flanged fittings and valves. Flanges used in North America for plumbing and heating/cooling systems generally conform to ASME B16.5 bolting patterns. These are sometimes referred to as "ANSI bolt patterns[1]".

1.0 INTRODUCTION

Bolted flanges are a common method for joining metal pipes to metal pipes, fittings, and valves. Flanges can also be used to transition from plastic piping materials, such as polypropylene (PP), to other plastic materials (e.g., CPVC, HDPE) and metal.

The design and selection of components for flanged joints connecting polypropylene pressure pipe-to-pipe (i.e., PP-to-PP), including the material types classified as PP-R & PP-RCT, or PP pipe-to-metal pipe (e.g., steel) are based on lower interfacial pressures than those used for metal-to-metal flanged joints. The initial interfacial pressure is limited by the allowable short duration stress of the gasket material and the PP flange adapter.

This PPI Technical Note focuses on the design and installation practices for transitioning from polypropylene pipe conforming to industry standards ASTM F2389[2] or CSA B137.11[3], to pipes, fittings, or valves of other materials using flange adapters and connections.

[1] ASME B16.5 *Pipe Flanges and Flange Fittings: NPS ½ through NPS 24, Metric/Inch Standard* previously published as ANSI B16.5 and ASA B16.5
[2] *Standard Specification for Pressure-rated Polypropylene (PP) Piping Systems*
[3] *Polypropylene (PP-R & PP-RCT) pipe and fittings for pressure applications*

2.0 ACRONYMS AND TERMINOLOGY

- ASME American Society of Mechanical Engineers
- BCD bolt circle diameter
- BFV butterfly valve
- BR backing ring (also known as “back-up ring”)
- CFG compressed fiber gaskets
- DVS Deutscher Verband für Schweißen und verwandte Verfahren e. V. ("German Welding Society")
- FA flange adapter
  FRP fiberglass reinforced pipe (Glass-Fiber-Reinforced Thermosetting-Resin Pipe)
- GF glass fiber
- LJF lap joint flange
- ID inside diameter
- MSF minimum seating force
- OD outside diameter
- WNRF weld neck raised face
- MOBL maximum operating bolt load
- MSF minimum seating force
- PP polypropylene
- PP-R polypropylene random copolymer
- PP-RCT polypropylene random copolymer with modified crystallinity and temperature resistance
- PP flange adapter PP fitting which provides a flange connection on one end by use of adapter a backing ring or lap-joint flange (Van Stone type flange) and straight pipe stub or socket fusion connection on the other end
- PTFE polytetrafluoroethylene
- EPDM ethylene propylene diene terpolymer
- CSM chlorosulfonated polyethylene (also CSPE)
- FPM fluoropolymer (also FKM)

3.0 PRINCIPLES OF POLYPROPYLENE FLANGED CONNECTIONS

The mating interfacial surface area of a metal-to-PP flange adapter may be significantly less than that between PP-to-PP flange adapters, since the bore (i.e., inside diameter) of the metal flange and pipe is typically larger than the bore of the PP flange adapter. Because of this, the required bolt and nut force of a PP-to-PP flanged joint may be greater than for PP-to-metal flanged joints due to the larger interfacial surface area. See Section 11.1 for additional discussion about this topic.

To establish higher long-term interfacial stress, retorquing is suggested to compensate for the stress relaxation in the PP flange adapters and gaskets.

While retightening of the bolts is recommended for all flanged joints, the creep relaxation of the PP flange adapter can significantly reduce the stress between the mating faces and loosen the bolts. Consequently, retightening is more important with PP flanged joints than with metal flanged joints.

Most PP flange adapters are provided with an internal taper/bevel to allow for rotation of the butterfly valve (BFV) disc when connecting to a BFV. In some cases, it may be necessary to provide a spacer ring with a tapered bore to provide clearance for the disc. The flange adapter manufacturer may also require the use of a gasket in addition to the integral seal of the butterfly valve. Consult the BFV manufacturer’s instructions to confirm proper sealing materials and bolt torque. Where discrepancies exist between BFV and flange instructions, consult with the manufacturers of both products to confirm correct installation procedures.

4.0 INSTALLATION INSTRUCTIONS – FLANGE TO FLANGE

4.1. Alignment of Flanged Joints

a. Proper alignment of all joint members is an essential element of proper flange joint assembly.
b. When achieving proper alignment requires more force that can be exerted by hand or common hand and hammer alignment tools, consult the PP piping manufacturer for guidance.

4.2. Inspect the flange adapter sealing surfaces

a. Check the adapter for tool marks, dents, or scratches.
b. Radial tool marks on the sealing surface are difficult to seal against, regardless of the style of gasket.
c. Ensure that the finish is adequate for the style of gasket being used.

4.3. Examine the gasket

a. Verify that the gasket material is compatible with the fluid being used in the pipeline and consistent with the sealing stress used for bolt torque values.
b. Check for tool marks, shipping, and storage damage. Discard any damaged gaskets.

4.4. Inspect and clean the bolts, nuts, and washers

a. Provide washers for each side of the bolt and nut assembly.
b. Lack of washers will affect the bolt torque required to achieve proper compression of the sealing surfaces.
c. Inspect all bolts, nuts, and washers to ensure they are free from damage. Discard any damaged components.

4.5. Lubrication of Threads and Nut contact surfaces

a. For coated bolts and nuts being used for the first time, the factory-installed coating of polytetrafluoroethylene (PTFE) or polyamide/amide is sufficient surface lubrication. Additional lubrication is not necessary, unless the bolts or nuts are being re-used.
b. For non-coated bolts and nuts, or if bolts or nuts are being reused, lubricate the bolt threads and the nut contact surfaces. Do not install bolts and nuts without lubrication.
c. The nut factor **0.16** is appropriate for coated bolts and a nut factor of **0.20** is appropriate for non-coated bolts.
d. Torque values found in **Table 3** only apply for the initial tightening of lubricated or new coated bolts.

4.6. Installation of Bolts

a. Bolts, washers, and nuts should be installed so that they are hand-tight with the marked end of the bolts and nuts located on the same side of the joint and facing outward to facilitate inspection.

4.7. Tightening of Bolts

a. Bolts should be tightened by securing the bolt in place and tightening/turning each nut by hand to prevent cross threads.
b. Multiple rounds of tightening should be used to ensure uniform bolt tightness.
c. After hand-tightening, a minimum of three (3) rounds of incremental tightening with a suitable torque wrench is recommended, tightening to approximately 30% of the target torque value on the first round.
d. Tighten to 50% to 70% of the target torque value on the second round, and to tighten to 100% of specified torque value on the third round.
e. After the third round, it is recommended that each bolt should be retorqued to 100% in a circular pattern to ensure that no bolts were inadvertently missed during the tightening sequence.
f. If a bolt or nut still turns at the target torque value, continue tightening until an increase in torque is observed.
g. In addition to performing the final torque tightening pass at 100% or torque value, measurements of the gaps between the flanges should be taken to verify that the flanges are being brought together evenly (i.e., parallel). Measurements of this gap at eight (8) equally spaced locations are recommended.

NOTE 1: When the target torque value is extremely high (e.g., above 300 ft-lbs.), additional tightening rounds should be considered to avoid deflecting or distorting the flange or backing ring and creating misalignment.

NOTE 2: Under no circumstances should bolt tightening be used to close the gap or "cinch up" the gap between flange faces or components.

4.8. Tightening Sequence of Bolts

a. The tightening sequence for bolts and nuts is based on usage of a single tightening tool, tightening one bolt at a time.
b. The “Legacy PCC-1” cross-pattern tightening sequence and bolt numbering system, when using a single tool, is shown in Table 4 of **ASME PCC-1**. It is included here as **Table 1** for convenience.
c. Only the portion of ASME PCC-1 Table 4 indicating up to 28 bolts has been included, since that is the number of bolt holes associated with a nominal 28 in. (i.e., 710 mm) pipe diameter.

There have been successful implementations of joint assembly patterns and torque-increment combinations that require less effort than the “Legacy PCC-1” method. The reader is referred to Appendix F of PCC-1 *ASME Guidelines for Pressure Boundary Bolted Flange Joint Assembly* for these alternative patterns.

Table 1: PCC-1 Legacy Cross-Pattern Tightening Sequence and Bolt Numbering System When Using a Single Tool

No. of Bolts	Sequentially Clockwise Sequence						
4	1-3-2-4						
8	1-5-3-7	→ 2-6-4-8					
12	1-7-4-10	→ 2-8-5-11	→ 3-9-6-12				
16	1-9-5-13	→ 3-11-7-15	→ 2-10-6-14	→ 4-12-8-16			
20	1-11-6-16	→ 3-13-8-18	→ 5-15-10-20	→ 2-12-7-17	→ 4-14-9-19		
24	1-13-7-19	→ 4-16-10-22	→ 2-14-8-20	→ 5-17-11-23	→ 3-15-9-21	→ 6-18-12-24	
28	1-15-8-22	→ 4-18-11-25	→ 6-20-13-27	→ 2-16-9-23	→ 5-19-12-26	→ 7-21-14-28	→ 3-17-10-24

4.9. Relaxation and re-tightening

a. All gaskets relax after tightening and seating.
b. Retightening the flange bolts is recommended to compensate for the relaxation of gaskets.

4.10. Increasing bolt torque

a. If leakage of any joint occurs after reaching the recommended flange bolt torque, bolt torque may be increased by 10% and the bolts retightened to the new higher torque in the same sequence as noted above.
b. A maximum of 20% increase above the recommended torque may be used.
c. If leakage of the joint still occurs, the connections should be disassembled, all parts examined for defects, replaced if necessary, and reassembled as noted above.

5.0 INSTALLATION INSTRUCTIONS – FLANGE TO BUTTERFLY VALVE (BFV)

5.1. Preassembly

When preparing to connect a BFV to a flange adapter, dry fit the connecting pipe flange adapters and the valve on a bench to ensure proper alignment prior to the actual valve installation. The flange adapter will typically have an internal bevel/taper to accommodate rotation of the butterfly valve disc (see also Note 3).

a. Provide bolts and washers/nuts for each bolt as required.
b. If the manufacturer of the flange adapter or butterfly valve (BFV) recommends using a gasket in addition to any integral seal, position the recommended gasket between the BFV and flange face on each side.
c. Install the bolts and washers/nuts and hand-tighten only.
d. With the flange faces in contact with the butterfly valve/gasket, operate the valve to fully open and closed positions a few times to check for interference and binding.
e. If there is interference or binding during valve operation, adjust alignment and spacing to ensure proper operation before continuing. If proper operation is not possible, a spacer may be necessary (see Note 3).

NOTE 3: A ring spacer is typically an HDPE or PP ring with the outside diameter (OD) matching the flange hub OD, and the inside diameter (ID) matching the ID of the butterfly valve. The ID may also be tapered to match the pipe ID on one end and the valve ID on the other. Once installed, the spacer allows full rotation of the valve disc.

5.2. Installation Steps for Flange to BFV

a. Dis-assemble the components and install them in the pipeline system.
b. Position the pipe flanges with enough space to allow the valve body to be positioned between the flanges without actually contacting the flange surfaces. In particular, be careful in handling the valve so that the neither the valve seat faces nor the disc are damaged.
c. Install all the bolts and washers between the valve and the flanges. Hand-tighten the bolts only as necessary.
d. Before completing the tightening of the bolts with a wrench, the valve should be carefully opened and closed again to ensure that there is no interference between the valve disc and the flange adapter.
e. If any interference occurs, loosen the bolts as needed, move the valve body slightly to adjust/center the valve and eliminate the interference. Re-tighten the bolts.
f. Following the procedure given in Section 4.7 Tightening of Bolts and following the sequence shown in **Table 1**, tighten the bolts evenly to ensure uniform compression of the valve seat against the flange adapter.
g. Once the valve bolts have been completely tightened, cycle the valve open and closed to ensure that the valve operates fully through its complete range of motion and that no binding is occurring.

6.0 PRESSURE-TESTING & LEAK CLOSURE GUIDELINE

Upon initial successful leak-free completion of the flange joint, the system should be operated at normal operating conditions (pressure, temperature, vibration, expansion/contraction) for 24 to 48 hours, and then bolt torques should be re-checked and re-tightened to the specified value(s) if any changes have occurred.

Normally, after initial tightening of bolts and the re-torquing 24 to 48 hours after initial installation, pressure testing per the manufacturer’s instructions is conducted. If pressure testing is done prior to re-torquing the bolts, each flange joint should be re-torqued after 48 hours.

If drip or spray leaks are discovered during pressure testing, the principle corrective action is to measure the existing bolt torque with a torque wrench, increase it by 10% to 15%, and apply that larger torque to the bolt(s) in the center of the leak and to each side of the leak. Tighten each bolt adjacent to those bolts slightly more. Repeat, slightly increasing the torque on the bolts neighboring the leak, until the leakage stops and the pipeline remains sealed.

Do not loosen the bolts on a pressurized pipe system! However, if 150% of the specified torque value is reached and the flange assembly still leaks, stop the pressure test, de-pressurize, and safely disassemble the flange joint. Something else, such as piping or gasket misalignment, is likely the cause of the leak.

WARNING: Safety around pressurized pipelines is of primary concern. Strategies for fixing leaking pipelines must always include the safety manager and possibly the corporate OSHA representative to ensure the maximum safety and the minimum chance of an injury or accident. Procedures should be sufficiently thought through and rehearsed and re-checked by project management before performing the work-plan so as to avoid accidents, injury, or even death.

7.0 FLANGE DISASSEMBLY

After bolts are tightened, the assembled flange is under tremendous compression. The PP flange adapter face wants to recover to its pre-compression thickness. If one bolt is removed, its compressive load is transferred to the two adjacent bolts, increasing their tension by approximately 33%. If a second adjacent bolt is removed, the additional compressive load is transferred to the remaining two adjacent bolts, increasing their tensile load by 50%.

Very quickly, one can see that loosening multiple bolts completely will over-load adjacent bolts, which could result in one or more of the following situations:

- Bent bolts or studs,
- Permanently stretched (yielded) bolts or studs,
- Permanently distorted/damaged metal backing lap-joint flanges, and
- Permanently distorted/damaged PP flange-adapter face.

The correct disassembly protocol is to reverse the assembly process. Using the tightening sequence, rotate each nut in sequence to loosen the fasteners by about 10 to 30 degrees, which is typically less than one-half of a flat on a six-sided nut. Repeat this several times until the assembly torque is gradually and evenly diminished, and the PP flange face is gradually and evenly unloaded.

WARNING: When working on pipelines that transport pressurized fluids, the contained energy may be dangerous to workers. Typically, a pipeline is depressurized before it is worked on to avoid injury in the event of a leak. Never tighten nor loosen a flange joint while the pipeline is pressurized. Always de-pressurize the pipe section before tightening or loosening flange bolts.

Once the fasteners are loose, the PP flange-adapter should pull free from the mating flange without the use of tools.

DO NOT USE WEDGE TOOLS to separate the flange adapters, as such tools will damage the sealing surface area.

DO NOT HAMMER the pipe wall to "shake" the pipe loose. Once loosened, the PP flange adapter's face seal surface should be protected from gouging or marring in a manner acceptable to the maintenance/project superintendent.

The un-bolted flange and pipe should be supported to bear the weight of the pipe, flange, and backing ring/lap joint flange (BR / LJF). The backing ring should not rest on the ground, bearing the weight of the pipeline on the "thin" inside diameter edge of the lap-joint flange. The nuts, washers, and bolts (or studs) should be cleaned and examined to see if they may be re-used, as corrosion may have damaged them. They may need to be replaced upon flange re-assembly.

Corroded threads are not only potentially weakened, but the corrosion will also create excessive friction that will dramatically reduce the amount of bolt-load (sealing force) generated on the gasket. New fasteners are highly recommended. If used fasteners are re-used, installers should take the time to fully clean the threads of the studs, bolts, and nuts, inspect for damage and replace as necessary, and properly lubricate the threads to achieve optimum loading and accurate torque values.

8.0 FLANGED JOINT PRESSURE RATINGS

ASME B16.5 *Pipe Flanges and Flange Fittings: NPS ½ through NPS 24, Metric/Inch Standard* provides pressure ratings for metal flanges that vary by flange material type. The standard does not provide pressure ratings for flanges made of non-metallic materials such as polypropylene (e.g., PP-R and PP-RCT).

The PP flange adapters will typically be designed with wall thickness equal to or greater than the connecting PP pipe. This is done to help ensure that the flange adapter body will meet or exceed the rated pressure of the connecting PP pipe. However, the flange joint itself is designed to be connected to ASME B16.5 flanges, which typically have either Class 150 or Class 300 bolt patterns.

The bolt torques and gasket materials are specified based on this anticipated maximum operating pressure (i.e., pressure class) of 150 psi or 300 psi respectively, rather than the actual pressure rating of the pipe. While these operating pressures are normally lower than the pipe rating, at higher temperatures the pipe rating may be less than the ASME B16.5 flange pressure class. The lower pressure rating must always be used as the overall maximum rating of the flange joint assembly.

In a metal piping system with flanged connections, Class 300 flanges would be used at "higher" service conditions. The geometry of a Class 300 flange has a bolt circle diameter (BCD) that is larger than the Class 150 BCD and, in some sizes, may use more bolts or larger bolt diameters than Class 150 flanges. The geometry of a Class 300 metal flange makes sense with metal flanges, because of the rigidity of these materials. However, the increase in BCD with a Class 300 pattern may make it more difficult to seal a flanged joint involving a PP flange adapter. Deformation of the flange face reduces the interfacial pressure near the inside diameter.

Consequently, the designer should consider using ASME B16.5 Class 150 flanges when the service pressures exceed the pressure rating of the metal flange, since there is a high factor of safety associated with metal flanges.

A **PP pressure pipe-to-PP pressure pipe** flanged joint (See **Figure 1**) consists of:

- Two polypropylene flange adapters
- Two loose metal backing rings (BR) often called Lap-Joint Flanges (LJF)
- Gasket per PP flange adapter manufacturer's specifications
- Bolt set (bolts or studs, washers, and nuts)

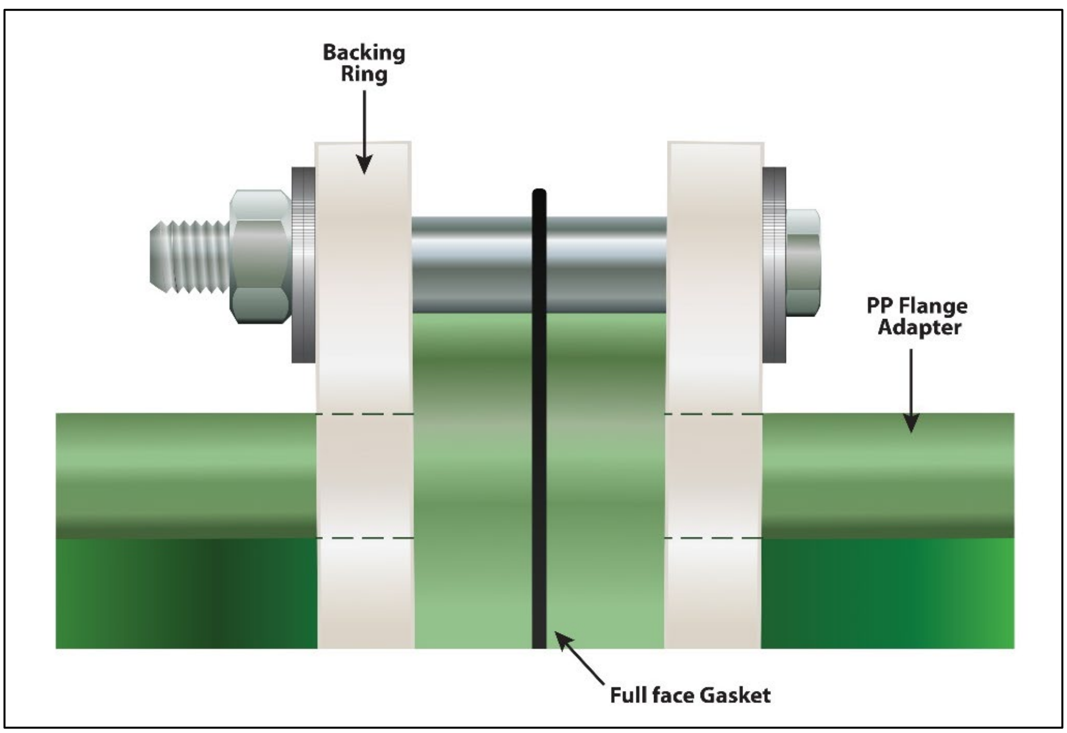


Figure 1: PP Flange Adapter to PP Flange Adapter joined using gasket and bolts

A **PP pressure pipe-to-metal** flanged joint (See **Figure 2**) consists of:

- One polypropylene flange adapter
- One loose metal backing ring (BR), often called a Lap-Joint Flange (LJF)
- PP spacer (if valve disc requires clearance and PP flange adapter is not modified, **Figure 4**, to accommodate this)
- Gasket per PP flange adapter manufacturer's specifications
- Metal flange or flanged fitting
- Bolt set (bolts or studs, washers, and nuts)

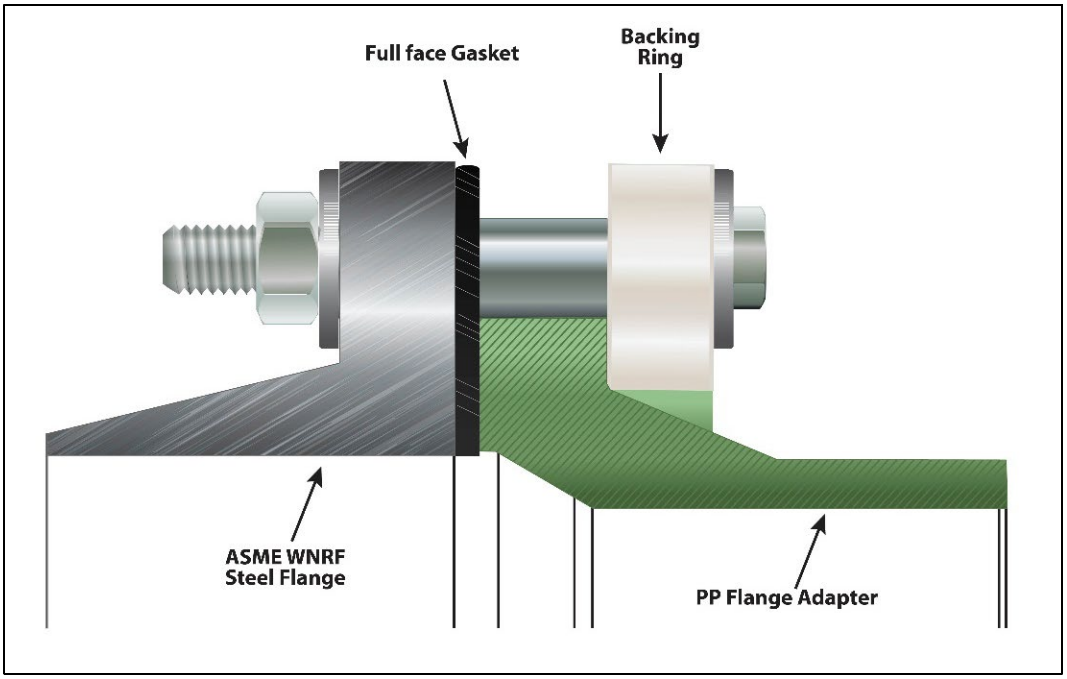


Figure 2: PP Flange Adapter to ASME WNRF Steel Flange

A **PP pressure pipe-to- plastic or -FRP** flanged joint consists of:

- One polypropylene flange adapter
- One loose metal backing ring (BR) often called a Lap-Joint Flange (LJF)
- Gasket
- Plastic or FRP flange or flanged fitting
- Bolt set (bolts or studs, washers, and nuts)
- Flange Spacer (if plastic or FRP flange is full flat face)

The interfacial (mating) surface of a PP-to-PP flanged joint is significantly larger than the interfacial surface of the PP-to-metal raised face (RF) mating flange. This is because the bore of a PP pipe and a PP flange adapter are smaller than a metal pipe with the same outside diameter and pressure rating.

The short-term allowable stress of PP determines the force required to seat/seal the flange. Consequently, a PP-to-PP flanged joint requires significantly more bolt torque to seat than a PP-to-metal RF flanged joint. This will be discussed further in the section describing bolt torque calculations.

9.0 FLANGED JOINT COMPONENTS

9.1. Flange Adapters

PP flange adapters (see **Figure 3**) and the backing ring inside diameter (ID) are typically made in accordance with ISO 9624 *Thermoplastic piping systems for fluids under pressure – Flange adapter and loose backing flanges – Mating dimensions*.

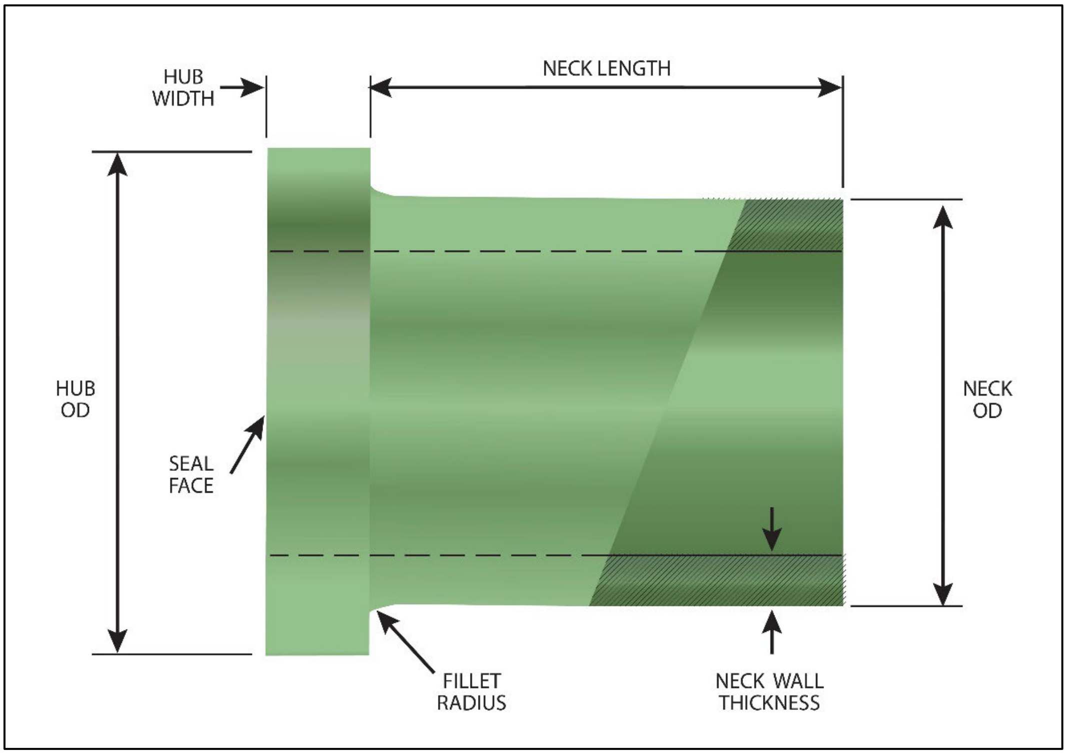


Figure 3: Polypropylene Flange Adapter Geometry

This standard also includes requirements for gaskets, marking and installation, including alignment, bolt patterns and torque application. The bolt pattern portion is not used for backing rings in North America. The rings are modified to accommodate the ASME B16.5 bolt patterns.

The internal diameter of the flange hub may also be modified to accommodate butterfly valves made to North American standards. See **Figure 4**.

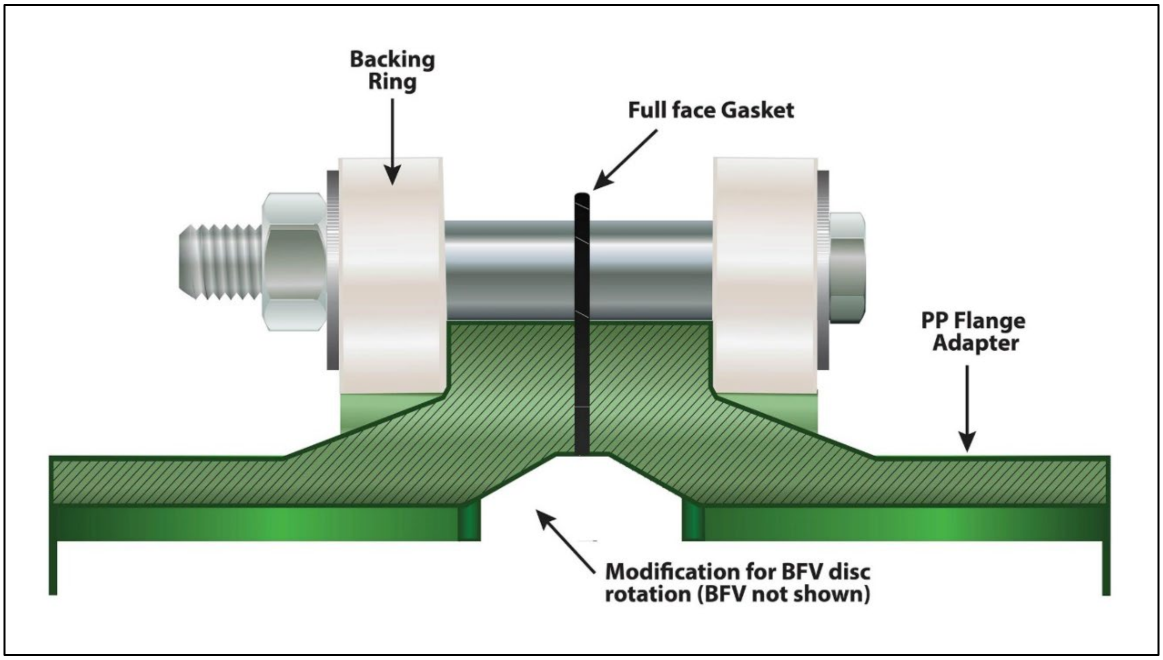
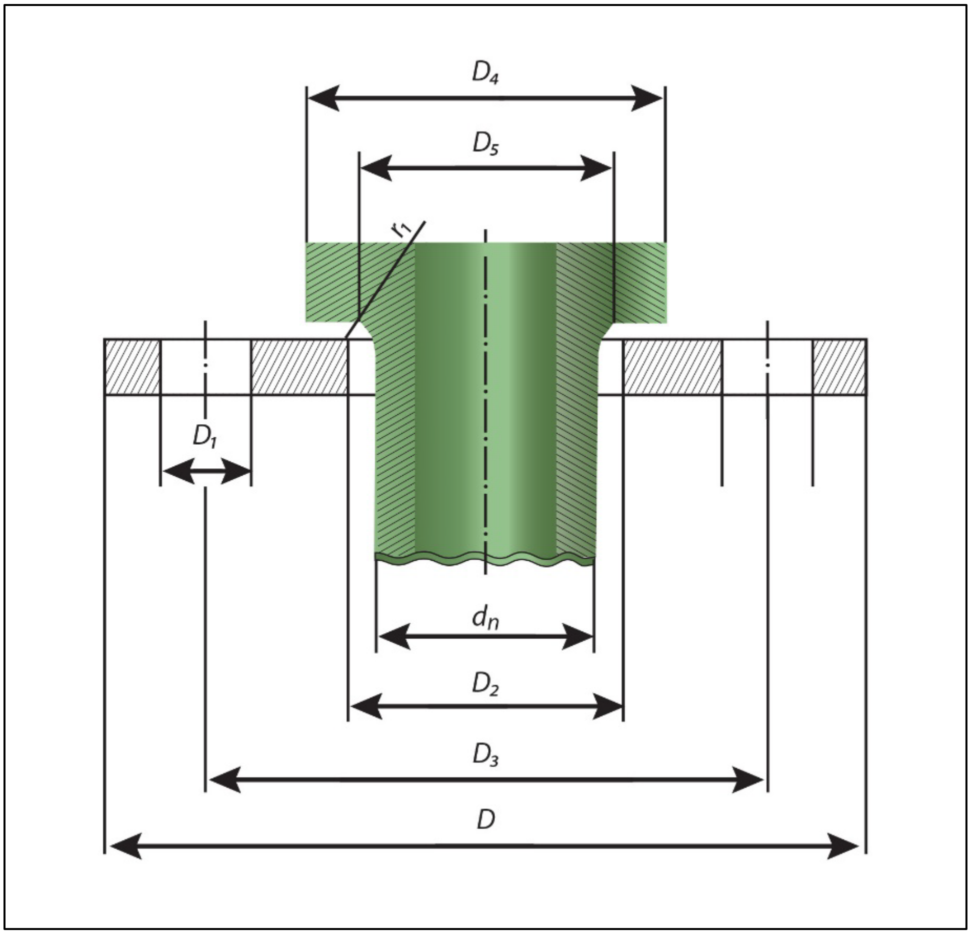


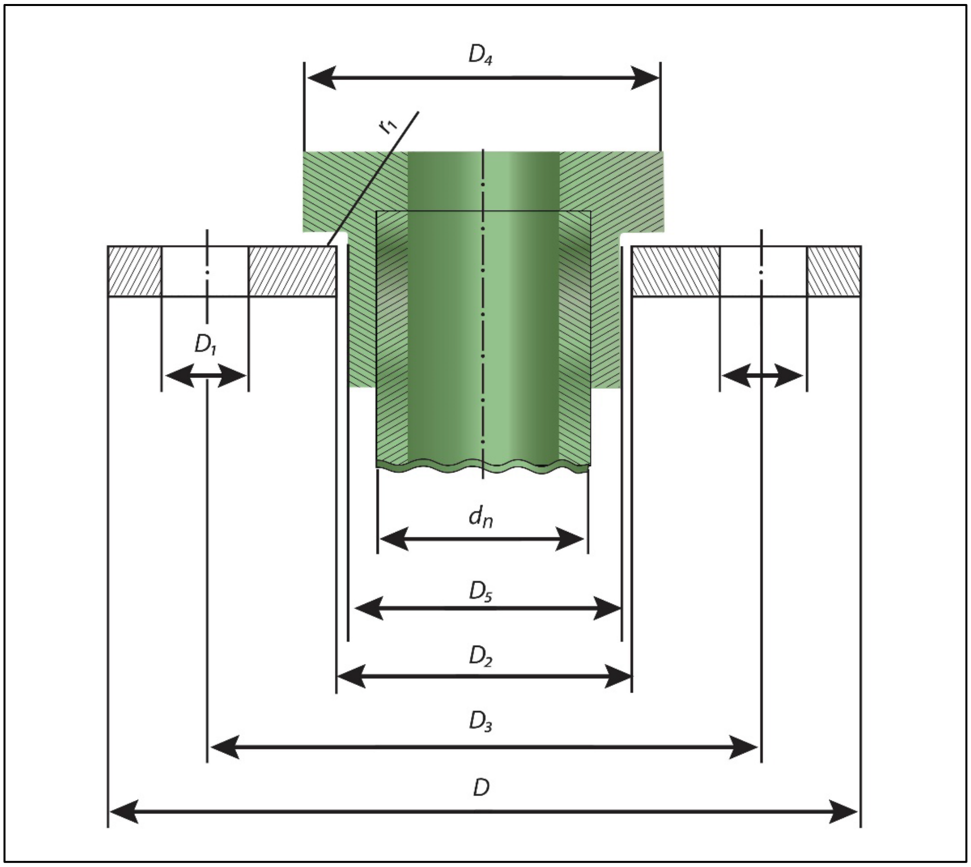
Figure 4: Flange adapter modified to accommodate butterfly valve disc

DVS 2210-1, Supplement 3 *Industrial piping made of thermoplastics - Design and execution, Above-ground pipe systems - Flanged joints: Description, requirements and assembly* also includes requirements for flanged joints. Many of these requirements are included later in this Technical Note.



d_n Nominal (outside) diameter of connecting pipe
D outside diameter of loose backing flange
D_1 bolt hole diameter
D_2 inside diameter of loose backing ring
D_3 bolt circle diameter
D_4 outside diameter of flange adapter hub
D_5 outside diameter of flange adapter neck
r_1 radius of shoulder of flange adapter

Figure 5: Geometry of a butt fusion flange adapter with backing ring



d_n — Nominal (outside) diameter of connecting pipe and nominal (inside) diameter of the socket
D — outside diameter of loose backing flange
D_1 — bolt hole diameter
D_2 — inside diameter of loose backing flange
D_3 — bolt circle diameter
D_4 — outside diameter of flange adapter hub
D_5 — outside diameter of flange adapter neck/socket
r_1 — radius of shoulder of flange adapter

Figure 6: Geometry of a socket fitting flange adapter with backing ring

The material (compound) requirements for PP flange adapters are the same as those of the pipe to which it is to be fused. Polypropylene has an apparent modulus that will decrease over time when the material is subjected to long-term loads at a constant temperature. Stress in polypropylene that is caused by straining the material (e.g., compression due to tightening of the flange joint bolts) will relax over time. This stress relaxation must be included in determining the bolt torque necessary for long-term seating stress on the gasket.

The PP flange faces should be inspected to ensure they are free from radial gouges. Some surface marring or denting is acceptable. The flange sealing faces should be free from rust, weld spatter, dirt, debris, etc. PP flange-adapter faces exhibiting surface marring or dents should limit such defects to not more than 1/16 inch (1.6 mm) deep.

Contact the supplier for assistance when minor defects are observed in PP adapter faces, as gaskets with a higher thickness or different hardness may be necessary to compensate for surface damage in the PP flange adapter face.

The flange faces should be cleaned and installed per the manufacturer’s recommendation. Flange faces should be uniformly flat and in consistent 90-degree orientation to the neck of the flange adapter.

9.2. Backing Rings (Lap Joint Flange)

The metal Backing Ring / Lap-Joint Flange cross-section geometry may be a contoured cross-section (See **Figure 7a**) or a rectangular solid with radiused corners (see **Figure 7b**) consistent with the flange shoulder/fillet radius in **Figure 3**.

The rectangular cross-section (see **Figure 7b**) is usually machined from metal plate and then coated to prevent corrosion. Alternatively, the backing ring may consist of a metal core with PP or PP-Glass Fiber (GF) over-molded. The ring dimensions must comply with the requirements in the final coated or molded configuration. This style of backing ring is much stiffer than the PP flange adapter (FA) hub. Tightening of the bolts causes compression of the PP hub without significant distortion of the metal backing ring.

The contoured cross-section (see **Figure 7a**) is typically cast using molten ductile-iron or stainless-steel. This style of Lap Joint Flange (LJF) backing ring cantilevers or rotates during bolt tightening. The decrease in bolt tension that would otherwise occur with distortion of the FA hub is therefore reduced with use of this flexible BR.

The effect is similar to that which occurs with Belleville washers (disc spring, spring washer). There are several producers of this product, and none provides any quantitative information about the relationship between the bolt load force associated with backing ring deformation.

These backing rings are an elastic, resilient, flexible “plate-spring” engineered to work with PP flange adapters. When the bolts are torqued, the LJF backing ring flexes and applies a uniform compression to the flange adapters.

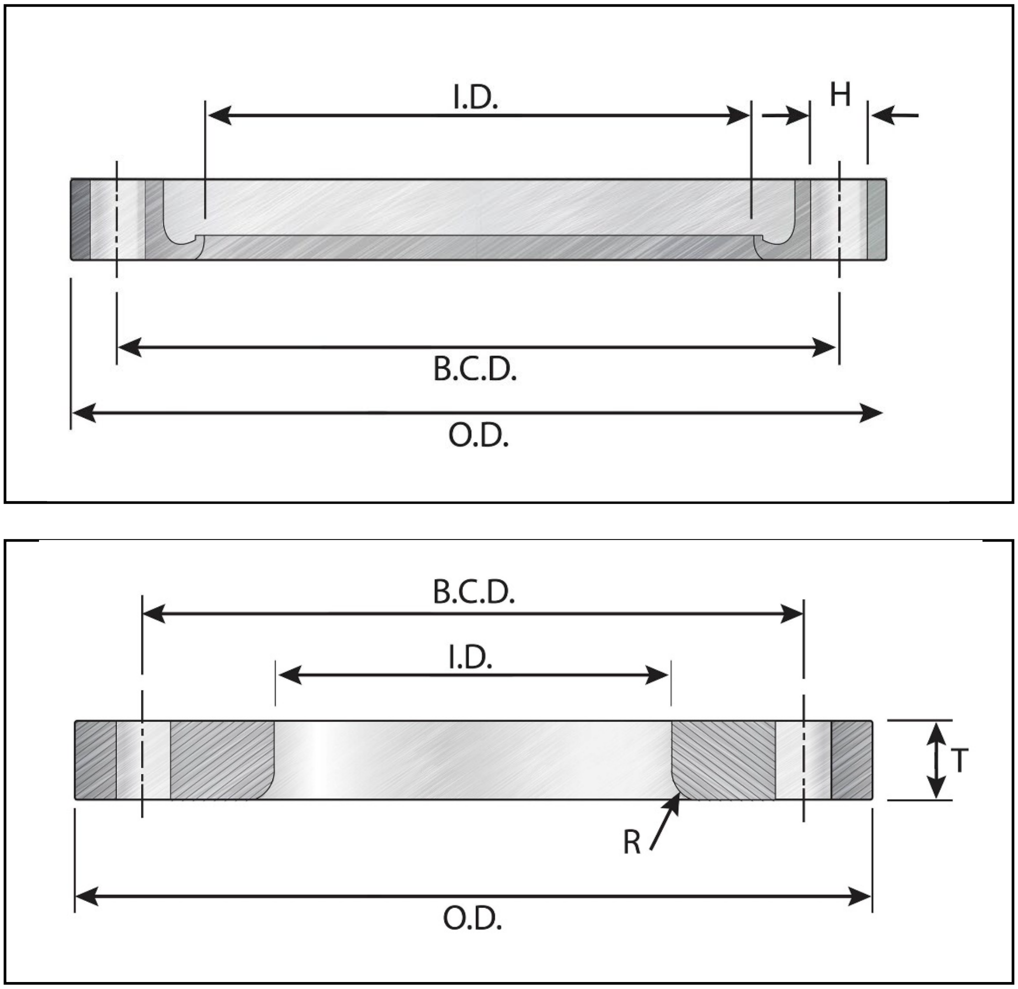


Figure 7a (top): Ductile Iron Convoluted LJF/BR
Figure 7b (bottom): Steel Plate BR

On an assembled joint, the BR/LJF is in contact with the underside of PP flange adapter hub and has a radius which mates with the fillet radius of the matching flange-adapter.

The BR/LJF slips over the pipe prior to its fusion to the FA. It is free to rotate so that it can be aligned with the bolt holes of the mating flange or BR.

Bolting patterns for backing rings are discussed in Section 4.8 Tightening Sequence of Bolts.

9.3. Spacer Rings / Butterfly Flange Adapters

When mating a metal flanged butterfly valve to a PP flange adapter (FA), the valve disc may physically interfere with the smaller bore of the flange adapter. A spacer ring with a taper on the inside diameter may be used as a transition piece to avoid this physical interference. The spacer ring may be machined from PP, or the hub width of the flange adapter may be increased to provide sufficient thickness to machine a taper on the FA for valve disc clearance.

It is more common to have an internal chamfer/taper on the PP flange adapter that will accommodate the valve disc rotation, rather than using a spacer. If the PP FA is designed to allow movement of the valve disc, the interfacial contact area will be reduced which will affect the required bolt torque.

9.4. Low Pressure Plastic & FRP Flanges

Low pressure plastic flanges (e.g., PVC, CPVC) are used on pipes and fittings made of these materials. These flanges are typically used on pipes NPS 24 and smaller with service pressures less than 60 psig (413 kPa). The flanges are often flat face (FF) and the mating flange should be flat face as well, to avoid creating bending moments.

Over-tightening, misalignment, or mating low pressure plastic flanges to flanges with raised face contact surfaces can potentially damage these non-metallic flanges. Extreme care is advised. Consult with the non-metallic flange manufacturer to determine the maximum torque limits, and if spacers are required when bolting them to PP flange adapters.

9.5. Bolts or Studs and Nuts

Since bolting material does not come in contact with fluid, its material compatibility with fluid in the pipe is not important. The selection of bolt material is determined based on service conditions. However, if the flange bolting will be exposed to corrosive environments (i.e., exposed to elements such as salt water), corrosion-resistant fasteners should be used. It is important for the bolting material to have sufficient yield strength to achieve the desired torque.

Dimensional standards usually adopted for fasteners are as follows:

- Studs/bolts: ASME B18.2.1
- Nuts: ASME B18.2.2
- Male Threads: ASME B1.1 Class 2A
- Coarse series (UNC): ASME B1.1 Class 2A
- Female Threads: ASME B1.1 Class 2A

Nut strength is designated as proof load. The “proof load” is defined as the maximum tensile force that can be applied to a bolt that will not result in plastic deformation. Nuts should be selected such that the proof stress of the nut is less than the yield strength of the mating bolt or stud.

When properly selected for compatibility, the nuts will yield well before the bolts and studs deform. At full torque, the first few threads of the nut take most of the load, and thus yield into the mating bolt threads. After one or more uses, the nut thread will not match the bolt thread due to distortional flow of the nut metal, such that the nuts should be replaced when re-connecting a critical connection.

Corrosion-proof nuts are available with coatings. Flange assembly corrosion-proofing (nuts & bolts) may also be applied after assembly.

Mating flanges are usually joined together with hex head bolts and heavy hex nuts, or threaded studs and heavy hex nuts. Generally, ASTM A307 Grade A or B hex head bolts are used to join flat face non-metallic flanges (no metal BUR), with full face elastomeric gaskets.

However, when installing compressed fiber gaskets (CFG) or PTFE gaskets in PP flange adapters with metal backing rings using the torque values shown in Section 11.3 based on achieving an initial gasket stress of 1,800 psi, carbon steel hex head bolts and heavy hex nuts, or all-thread rod with a minimum yield strength of 55,000 psi should be considered.

Common grades that would meet these requirements are SAE J429/A449 Grade 5, and ASTM A325 Type 1 (or 2, 3), and ASTM A193 (Grade B7 or Grade B8 Class 2). All-thread rod should be ASTM F1554 Grade 55, ASTM A36, or stronger. Corrosion-resistant materials should be considered for underground, underwater, or other corrosive environments. Flat washers should always be used with bolts and nuts.

The minimum bolt length required for a flanged PP joint should be the sum of the thickness of the backing ring(s), flange adaptor(s), metal flange, both nuts, washers, and the gasket thickness plus 1 bolt diameter. See **Figures 1** and **2**.

The addition of length equal to 1 bolt diameter provides an allowance for full engagement of all threads in the nut with visual verification, and minor deviations in thickness of materials. Bolt length should be rounded up to the nearest standard bolt length. Rounding down may result in bolts shorter than the required minimum length. Many companies require a minimum number of threads (often 3) and/or maximum number of threads (often 6) to be visible above the nut to ensure full thread engagement.

If threaded studs are used, then washers and nuts are installed on both sides.

The calculation of bolt torque depends on the “Nut Factor” or “k-factor” used to calculate to the target torque. Appendix K of PPC-1 *ASME Guidelines for Pressure Boundary Bolted Flange Joint Assembly* defines ‘nut factor’ as an experimentally determined dimensionless constant related to the coefficient of friction. The k-factor in most applications at ambient temperature is generally considered to be approximately equal to the coefficient of friction plus 0.04. **Table 1** of PCC-1-2000 indicates that nut factors of 0.20 to 0.16 are appropriate for non-coated and coated bolts, respectively.

An expanded list of nut factors may be found in Table 7.1 of Bickford's Text (Bickford, 2008) *Introduction to the Design and Behavior of Bolted Joints*.

It should also be noted that recent research has shown that nut factors, or "k" factors, can vary based on bolt material, bolt diameter, and assembly temperature. These factors can significantly impact the torque and resulting force calculations and should not be ignored when selecting a thread lubricant.

The end-user is advised to seek test results conducted on similar bolt and thread lubricant specifications or to conduct nut factor trials with their own conditions. Nut factor trials can be conducted relatively easily by tightening a bolt using known torque and measuring the obtained bolt load by calibrated ultrasonic measurement, use of a calibrated load cell, or measuring pressure rise on a hydraulic tensioner.

NOTE 4: PPI recommends that each flanged joint be independently analyzed by the responsible project engineer for sealing capacity when subjected to all expected installation, operating and environmental conditions/loads.

10.0 GASKETS

As used in this document, gasket refers to a flat or contoured static sealing component. A seal (n) is used for dynamic sealing where the mating surfaces are intended to rotate or move during use. Several international standards refer to gaskets used in flanged plastic piping systems:

- ISO 9624: "The gasket material shall be chemically and thermally compatible with the fluid in the pipe and have an appropriate hardness. Gaskets are often made of rubber materials, but some other materials are also approved for use. Attention is drawn to the joint design to allow the gasket to maintain its elastic behavior (ISO)."

- DVS 2210-1, Supp. 3: "When choosing a seal material, it is necessary to take account of the medium, the operating conditions, the properties of the seal material, the shape and surface finish of the sealing face as well as the loads on the flanged joint."

In plastic piping, preference should be given to the use of seals made of elastomer materials such as EPDM, CSM, or FPM with a Shore A hardness of 65 to 75. Seal materials with a higher hardness (e.g., as used in metallic piping) are often not suitable for thermoplastic piping.

If seals with a particular chemical resistance (e.g., made of PTFE) and whose preliminary deformation requires bolt-tightening torques above the values specified in Table 5 are to be used, it is recommended to consult the piping manufacturer. If in doubt, the operational safety of the flanged joint must be proven.

An operationally-safe seal with effective chemical resistance can be achieved by using modified PTFE seals. The properties of multi-directionally-oriented seals made of expanded PTFE (ePTFE) allow good conformity to the sealing faces with low bolting forces.

Seals with reinforcement can only be used if the load-bearing part is surrounded by the seal material. Due to their high preliminary deformation forces, fabric-reinforced elastomer seals tend to be unsuitable for flanged joints in plastic piping (DVS).[4]

The gasket material should be chemically and thermally compatible with the internal fluid and the external environment. It should be of the appropriate thickness, hardness, and style, and should be recommended by the gasket material manufacturer for use with polypropylene pipe flanges. ASME B16.21 gaskets may have a larger ID than the PP flange adapter ID (on smaller sizes), resulting in reduced contact area/bolt torque.

Generally, there are two categories of gaskets that are used in a PP flanged connection: elastomeric and PTFE gasketing.

Elastomeric gaskets may be homogeneous, reinforced with fabric, or include a metal retaining ring. Some elastomeric gaskets may also have raised ribs rather than a flat face to provide a higher sealing pressure with less bolt torque. While fabric reinforced elastomers do have better crush and extrusion resistance, the fabric may absorb and “wick” the pipeline fluid, resulting in a leak.

It’s important to choose a product that is designed to seal properly with an assembly stress of less than 1,500 psi, and soft enough to conform to the PP flange adapter sealing surface without causing damage to the surfaces. Gaskets with raised ribs or lower hardness material may have much lower sealing stress values, and the gasket manufacturer’s recommendations must be followed to avoid damaging the gasket.

Metallic gaskets should not be used with non-metallic flanged joints.

Gaskets should not be reused when a flanged joints has been in service and then disassembled for any reason. New gaskets should be installed when assembling the flange joint.

Another important factor to consider when selecting a gasket is the service media.

Many of the PP flanged connections in service are used for potable drinking water. Therefore, users should use gaskets certified to NSF/ANSI/CAN 61 *Drinking Water System Component – Health Effects* to avoid introducing contaminants into the drinking water.

[4] DVS Technical Code 2210-1, *Supplement 3, Industrial piping made of thermoplastics Design and execution Above ground piping systems Flanged Joints: Description, requirements, and assembly*.

Gaskets used on flange assemblies on some industrial and wastewater systems and on potable water systems may be exposed to chemicals such as chlorine or chloramines. The gasket materials should be selected to ensure there is chemical compatibility and to provide long-term usefulness and minimum degradation of the gasket specified (swelling, oxidation, loss of elasticity, or softening).

The gasket should be self-centering, which is accomplished by either using a ring or full-face gasket. A ring gasket will have an outer diameter equal to the bolt circle diameter minus the bolt diameter. This will allow the gasket to center itself by contacting the bolts once installed in the backing ring. A full-face gasket will have the same outer diameter, bolt circle, and bolt hole dimensions as the backing ring or flange. Therefore, once the bolts are installed through the backing ring and gasket, the gasket is properly positioned in the flange.

NOTE 5: Full-face gaskets are recommended as installers can hang/position the gasket on the bolts/studs, which holds the gasket in place while the other flange assembly is brought into place. Full-face gaskets will also reduce the potential for gasket extrusion and blow-out once the system is pressurized.

11.0 BOLT LOAD/TORQUE CALCULATION METHODOLOGY

The methodology for calculation of appropriate bolt loads (i.e., bolt torques) is to determine the load (force) required to produce an initial theoretically uniform seating stress across the mating interfacial surface area. This load is due to the accumulated axial load from the torqued bolts. The accumulated bolt load is the '**bolt stress'** times '**the number of bolts'** times '**the effective cross-sectional area of each threaded bolt'**. (See **Equation 1**)

The torque on the bolts is based on the 'nut factor' … the efficiency with which torque is converted to axial bolt load. Details of the methodology are found in Sections 11.2 and 11.3.

The calculated bolt torque is generally considered to be a minimum, with an allowable variation of +20%. The flange adapter manufacturer and gasket manufacturer specifications should be consulted for specific values and tolerances.

The bolt torque includes an allowance for stress relaxation in the interfacial pressure used. That is, the interfacial pressure must include the seating stress required for the gasket as well as any losses or decrease due to stress relaxation of the gasket and flange adapter and nut/bolt movement. Changes in system operation such as thermal expansion or expansion due to internal pressure are not explicitly included here.

11.1. Rationale for this Methodology

Calculation of the bolt torque for flanged joints in **metal piping systems** is based on "…the ASME design philosophy for flanged joints. The method involves determining the load on the flange bolts and ensuring that the selected flange bolts (size and material) can withstand the bolt load without exceeding Code allowable stress values.

For the determination of bolt load, two cases are considered: the required bolt load for design conditions, Wm1, and the required bolt load for gasket seating, Wm2" (The ASME Boiler and Pressure Vessel Code, Section III, Appendices, 2015).

- The bolt load (**Wm1**) that is required to resist the operating pressure, surge pressure, pipe-line axial thermal contraction, and pipe bending strain from soil settlement, and flange angular alignment; all with an applied safety factor is the Maximum Operating Bolt Load (MOBL).
- The bolt load (**Wm2**) that is required to provide the appropriate seating force required for the interfacial sealing surface stress is the minimum seating force (MSF).

An EPRI report, *Capacity Testing of High-Density Bolted Flanged Joints* (J. D. Stevenson and Associates, Inc. & Munson and Associates, 2010) concluded that the minimum operating bolt load never becomes a factor in the analysis at the working pressures considered in their report (150 psi) and never produces a MOBL requiring an interfacial pressure greater than that required to seal the joint assembly. The same report used finite element analysis (FEA) calculations to determine the target interfacial pressure required to seal a PE pipe to metal pipe connection.

As noted in the discussion in Section 9.1, PP stresses will relax over time and reduce to about 35% of the initial stress value in 1,000 – 4,000 hrs. In addition, the relatively thick PP flange adapter will strain by an amount that eliminates the strain that occurs in the bolts during initial bolt tightening. Retightening is suggested to compensate for the initial PP stress relaxation / PP straining.

In addition to the strain occurring along the axis of the pipe, there is deformation of the flange adapter caused by eccentric loading of the bolts, backing ring and gasket seating. In their FEA-based assessment of flanged joints for large pipes (Jacobsson, 2011) the authors concluded that due to deformation of the PE flange adapter "the contact (along the interfacial sealing surfaces) is lost along a large part of the joint already from the beginning of pressurization of the pipe".

The authors concluded, as well, that the most efficient way to improve the joint is to increase the bolt torque and to maintain the seating stress by re-tightening or by use of flexible backing rings.

After consideration of the conflicting information in these reports, the PPI task group assessing this information has concluded that determination of the appropriate bolt torque for sealing flanged joints involving PP flange adapters cannot be assessed by employing the ASME methodology applicable to metal flanged joints.

NOTE 6: Industry experience has been that determination of bolt torque using the Minimum Seating Force (MSF) approach, based on a target interfacial pressure is the best practical way to determine the target bolt torque. The target interfacial pressure for most applications is 1,200 psi. An appropriate 'nut factor, K' should be selected to determine the bolt torque. For low pressure applications (<60 psig) using an elastomeric gasket, a maximum interfacial pressure of 900 psi may be used.

Retorquing several hours after assembly is required.

NOTE 7: Inspection of assembled flanges and retorquing the bolts several hours after operation at design conditions is recommended.

11.2. Nut Factors

Table 1 of the Guideline document (PCC-1 *ASME Guidelines for Pressure Boundary Bolted Flange Joint Assembly*) indicates that 'nut factors' correspond approximately to 0.20 and 0.16 for non-coated and coated bolts respectively.

The report notes that "…recent research has shown there to be nut factor dependence on bolt material, bolt diameter, and assembly temperature. These factors can be significant and should not be ignored when selecting the nut factor or anti-seize compound. The end user is advised to seek test results conducted on similar bolt and anti-seize specifications or to conduct nut factor trials with their own conditions. Nut factor trials can be conducted relatively easily by tightening a bolt using torque and measuring the obtained bolt load by calibrated ultrasonic measurement, use of a calibrated load cell, or measuring pressure rise on a hydraulic tensioner".

PPI recommends a nut factor (K) of **0.16** for non-plated bolts and studs that are lightly greased. The table of calculated bolt torque presented in this Technical Note are based on a K of 0.16.

NOTE 8: Other standards may use different K values for the friction coefficient. For example, DVS 2210-1, Supplement 3, refers to an average friction coefficient of 0.15.

11.3. Calculation of Target Bolt Torque

The "Target Torque" values in **Table 3** are those required to provide an initial seating stress of 1,200 psi. Other gasket materials or contour/profile gaskets may have other seating stress or bolt torque requirements, and the gasket manufacturer should be consulted. The nut factor used to convert *bolt load* to *bolt torque* is **0.16**.

If nut factors other than these values are determined to be suitable, the target torque may be determined by applying a factor that is the ratio of the desired nut factor / 0.16 times the torque value **Table 3**.

For flange assemblies consisting of two (2) PP flange adapters, the flange adapter ID will be the same on both contact surfaces and the surface area can be calculated directly. When connecting a PP flange adapter to a steel flange or other product/equipment, the contact area of the mating surfaces must be calculated.

When bolting to materials with lower ductility than PP, such as fiberglass / FRP, cast iron, CPVC/PVC pipe flanges, or CPVC/PVC flanged valves lower bolt torques may be required. Lower seating stresses than those used in this table may be appropriate for these flange materials. Consult the flange or valve manufacturer to verify their maximum allowable torque for the given flange.

12.0 EXAMPLE BOLT TORQUE CALCULATIONS

Determine the initial bolt torque for a flanged connection between two (2) 8-in (200 mm) DR 11 flange adapters with the following data provided:

- The interfacial contact area is the area between the ID and the hub OD of the flange adapter.
- The flange ID and OD dimensions are based on ISO 9624.
- The number of bolts and bolt diameter are based on ASME B16.5.
- The bolts are lightly greased so a ‘nut factor’ of 0.16 is used.
- The target interfacial pressure (IFP) is 1,200 psi.

Table 2: Specifications for Example

Flange adapter ID	6.44 in.
Hub OD	10.55 in.
No. of Bolts (n)	8
Bolt Diameter (d)	0.75 in.
Nut Factor (k)	0.16

Initial Bolt Torque (T) can be determined using the following equation from: (J. D. Stevenson and Associates, Inc. & Munson and Associates, 2010)

[Eq. 1]

$$T = \frac{k*d*\pi*\left(OD^2 - ID^2\right)*IFP}{4*n*12}$$

T = [0.16 *0.75 *3.14159* (10.55^2-6.45^2) * 1200] / [4 * 8 * 12] = 82 ft-lb.

Table 3: Target Torque values for Nut Factor 0.16,
Interfacial pressure 1,200 psi, Pipe DR 11

ASME B16.5 Pipe Size	Pipe OD	FA Hub OD*		FA ID		Number of bolts	Bolt dia.	Torque
	mm	mm	in	mm	in		in	ft-lb
1	32	68	2.677	26.2	1.031	4	0.50	10
1.25	40	78	3.071	32.7	1.288	4	0.50	12
1.5	50	88	3.465	40.9	1.611	4	0.50	15
2	63	102	4.016	51.5	2.029	4	0.63	24
2.5	75	122	4.803	61.4	2.416	4	0.63	34
3	90	138	5.433	73.6	2.899	4	0.63	41
3.5	110	158	6.220	90.0	3.543	8	0.63	26
4	125	158	6.220	102.3	4.026	8	0.63	22
6	160	212	8.346	130.9	5.154	8	0.75	51
8	200	268	10.551	163.6	6.442	8	0.75	82
10	250	320	12.598	204.5	8.053	12	0.88	86
12	315	370	14.567	257.7	10.147	12	0.88	100
14	355	430	16.929	290.5	11.435	12	1.00	163
16	400	482	18.976	327.3	12.885	16	1.00	152
18	450	528	20.787	368.2	14.495	16	1.13	196
20	500	585	23.031	409.1	16.106	20	1.13	192
24	630	685	26.969	515.5	20.293	20	1.25	248

**from ISO 9624:2019*
Hub OD for ND 18 must be reduced to accommodate ASME B16.5 bolt circle

13.0 REFERENCES

Introduction to the Design and Behavior of Bolted Joints. (Bickford, 2008)