US DOT PHMSA AID Situational Awareness for Employees: SAFE Bulletin[1]
Flange Assembly Failures[2]

49 C.F.R. Part 195 Transportation of Hazardous Liquids by Pipeline

Summary: The Pipeline and Hazardous Materials Safety Administration's (PHMSA) Accident Investigation Division (AID) is issuing this SAFE Bulletin to provide inspectors with information on accidents caused by flange assembly failures in hazardous liquid (HL) and gas transmission (GT) pipeline systems as well as information about a potential pipeline safety concern related to incorrectly marked ULMA manufactured A105 flanges.

A flange assembly consists of flange(s), gasket(s), nut(s), and bolt(s). Flange assemblies are used to mechanically connect pumps, meters, regulators, valves, pipe, and other appurtenances in a pipeline system. Flanges can be welded or screwed. Flanged joints provide a seal by bolting two flanges or a flange on either side of an appurtenance with a gasket between them. An advantage of the use of flanges over welded connections is the easy access to the connected appurtenance for cleaning, inspecting, or conducting modifications.

AID analyzed flange assembly failures in accident information from hazardous liquid reportable accidents from January 2010 through June 2020. Flange assembly failures were identified using the term *flange* under *Part C: Additional Facility Information, Numeral 3: Item Involved in Accident* in Form PHMSA F 7000-1. Although failures were listed as flange, they did not necessarily indicate a failed flange; the failure was most likely be related to a gasket failure or incorrect bolt torque. AID characterized hazardous liquid pipeline flange assembly failures as follows:

- During the last ten years, 219 of the 4,079 (5%) hazardous liquid accidents occurred where the *item involved in the accident* was a flange.
- Total property damage cost $93,807,768 and 26,800-barrels of unintentionally released hazardous liquid product. About half released outside the operator's property.
- Most (72%) flange assembly failures resulted in unintentional releases of less than 5-barrels but eight accidents were major releases of greater than 500-barrels. The three most costly spills represented $63,843,793 or 68% of the total costs.

[1]This bulletin is not intended to revise or replace any previously issued guidance. It is not legally binding in its own right and will not be relied upon by the PHMSA as a separate basis for an affirmative enforcement action or other administrative penalty, and conformity with the bulletin (as distinct from existing statutes and regulations) is voluntary only, and nonconformity will not affect rights and obligations under existing statutes and regulations.
[2] Flange assembly failures are identified as "Flange" under Part C: Additional Facility Information, Numeral 3: Item Involved in Accident in Form PHMSA F 7000-1.

- No fatalities or injuries were associated with flange assembly failures.
- The *area of accident* was aboveground 65%, underground 21%, and tanks/transition area 14% of the time. The use of flanges on underground pipelines is allowed, but it is not regarded as a good practice.
- The leading causes of flange assembly failures were equipment failure and incorrect operations.
    - Of the 126 failures caused by equipment failure, 107 were non-threaded connection failures (81 gasket and 26 seal/O-ring). In rare occasions, the flange or bolt (7) experienced a material failure. Flange and bolt material failures were mostly due to corrosion. Gasket material failures were also rare and were typically due to incorrect specification.
    - Of the 73 failures caused by incorrect operations, 34 were due to equipment not installed properly, 18 to other incorrect operations, and 12 to overpressure.
    - A predominant factor across the failures was detrimental induced stress on the flange assembly.
    - The foremost cause of the stress was incorrect torqueing of bolts (over compression, uneven torqueing, inadequate torqueing, incorrect sequence of bolting).
    - Other causes of stress on the flange assembly was due to thermal overpressure, overburden, misalignment of flanges, pipeline settlement, inadequate pipe support, overpressure, bending, and vibration.
    - Additionally, failures were due to incorrect gasket specification, damage related to hydrostatic pressure testing and in-line inspection tools, and incorrect installation/operation. Several of the incorrect operations occurred during simultaneous operations.

A comprehensive characterization and summary of the hazardous liquid pipeline flange assembly failures and mitigative actions gleaned from the accident narratives is in Appendix C – Detailed Summary of Accident Investigation Findings.

Although 19 gas transmission incidents involved the failure of flange assemblies, this only represents 1.5% of the total number of gas transmission incidents reported for the last ten years. Consequently, this bulletin does not include analysis of gas transmission flange assembly failures. Except for failures caused by thermal overpressure, the information culled from hazardous liquid pipeline accident reports will apply to gas transmission flange assemblies.

The Subcommittee on Railroads, Pipelines and Hazardous Material alerted PHMSA about incorrectly marked ULMA ASTM A105 flanges on October 31, 2019. The ULMA manufactured flanges were not normalized per ASTM A105/A105M[3] to obtain the proper mechanical properties such as toughness for cold weather applications. This would result in flanges with low toughness and shear properties. While there have been flange failures outside of the U.S., based on PHMSA's assessment thus far, there have been no known failures affecting systems under PHMSA's jurisdiction. Flanges manufactured by ULMA Forja (Spanish Corporation) or ULMA Piping (U.S. Corporation) failed on refinery and line pipe outside of the U.S. in cold operating temperature environments. Most, if not all, of these flanges were purchased through a 3rd party distributor. U.S. District Court for the Southern District of Texas ordered ULMA to recall the flanges. PHMSA's Engineering and Research Division, PHMSA PHP-80, requests that Inspectors and Investigators alert them of any flange failures due to manufacturing or mechanical defects found during construction or operational inspections, or incident investigations.

For Further Information, Contact: Alvaro Rodriguez 405-482-8440 Alvaro.Rodriguez@dot.gov

Supplemental Information:

Background

A flange assembly consists of flanges, gasket(s), nuts, and bolts. Flange assemblies are used to mechanically connect pumps, meters, regulators, valves, pipe, and other appurtenances in a pipeline system. Flanged joints provide a seal by bolting two flanges or a flange on either side of an appurtenance with a gasket between them. The use of flanges on underground pipelines is allowed, but it is not regarded as the best practice. An advantage of the use of flanges over welded connections is the easy access to the connected appurtenance for cleaning, inspecting or conducting modifications. Flanges can be welded or screwed.

AID found that correct torqueing of bolts was a frequent cause of flange failure assemblies. The bolting method for tightening flange bolts may involve the use of torque wrenches or hydraulic stud tensioners. Flange bolt holes are in multiples of four, equally spaced, and pairs of bolt holes straddle fitting centerlines. Proper torque values are based on different component characteristics, such as gasket material, flange size, flange type, bolt material, lubricant, etc. Torque values from gasket manufacturing recommendations must be followed if they are available.

The amount of torque should be applied evenly involving several steps. Methods vary and number of steps must be defined by operator procedures and recommendations of the gasket manufacturer. Figure 1 are examples of bolt tightening sequence across a flange.

[3] ASTM A105/A105M-18 - Standard Specification for Carbon Steel Forgings for Piping Applications

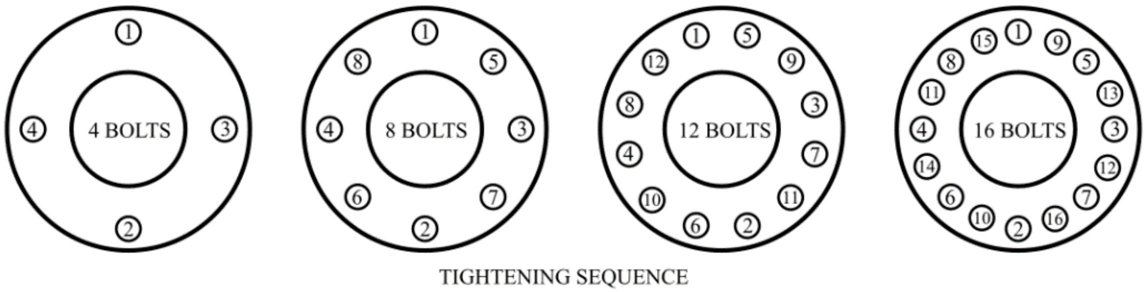

Figure 1 Tightening sequence of bolts across a flange.

The different types of flanges, gaskets, nuts and bolts are described in [Appendix A for Flange Assembly Technical Information.]

Accident Investigation of Flange Assembly Failures

Accident 1 – Corpus Christi, TX – 6/10/2020 (8.5-barrels)
In April 2020, the operator emptied the pipeline in preparation for a hydrostatic pressure test. The test was unsuccessful so the operator ran an ultrasonic technology (UT) in-line inspection tool. The tool located two underground flange assemblies. A layer of diesel was found 18-feeet belowground during hydro-excavation of one of the flange assemblies. On June 6, 2020, with the flanges exposed, a hydrostatic pressure test was conducted and an underground flange assembly leaked. The operator removed the flange assembly and initiated a failure analysis which is in progress. The pipeline remained out-of-service while the investigation and repairs were conducted. The estimated total costs were $255,000.

Accident 2 – Everton, MO – 01/14/2017 (450-barrels)
On January 14, 2017 at 10:18 a.m. CT, a Control Center operator received a leak detection alarm on a pipeline in Everton, MO, and shutdown and isolated the pipeline at 10:22 a.m. CT. An on-site employee confirmed the release of crude oil from the pipeline system.

The line operated at 300 psig at the point and time of the accident with an MOP of 779 psig. The underground interstate pipeline, located in a vault, spilled 450-barrels of crude oil from operator-controlled property, but the commodity migrated off the property, which was contained.

The cause of the release was due to a circumferential crack in the body of the flange (Figure 2) adjacent to the girth weld between the flange and the pipeline located on the upstream side of the mainline valve. The failed flange was made of carbon steel and installed in 1949.

The pipeline repair consisted of installing a 6-feet long flanged spool segment immediately upstream of the mainline valve. This fabricated assembly was hydro-tested prior to installation. The pipeline was returned to service on January 19, 2017 at 8:48 p.m. CT.

The total property damage accounted for $11,570,000, with more than $5 million used to remediate public property damage.

Figure 2 Circumferential crack in the body of a 1949 carbon steel flange. Photo provided by Operator.

Accident 3 – Drumright, OK – 09/19/2016 (22-barrels)

At approximately 6:45 a.m. CT on September 19, 2016, a pipeline operator (PL1) contacted the local technician of another operator (PL2) to notify of a possible release from their pipeline facilities. Such station was manned by PL1 through which PL2 crude system traverses and has several pumps.

The local PL2 technician contacted their control center and the pipeline was shut down immediately. The technician arrived onsite at 7:30 a.m. CT and confirmed the release in the interstate line.

An estimated 22-barrels of crude oil released from the underground line with the commodity totally contained in the operator’s facility. The released crude was removed and the sub-grade source identified via hydro-vacuuming. The cause of the release was determined to be a block valve flange, installed in the 1950's. The valve incorporated ring joint flanges while the connecting piping flanges were raised face. The gasket connecting the valve to the pipe was not a currently approved design for joining the two flange types.

Additionally, some of the bolts on the leaking flange were loose. The flange surfaces and gasket were inspected, replacing the gasket with one suitable for the configuration. The assembly was properly torqued, and the pipeline was restarted two days after. The other valves in the area were excavated to ensure flanged connections were properly torqued.

The pressure at the point and time of the accident was 736 psig, with a MOP of 807 psig. The total property damage was $317,000 with $101,000 on environmental remediation.

Accident 4 – Ventura, CA – 06/23/2016 (1,075-barrels)
Prior to the accident, the intrastate pipeline was shut-in, and purged with nitrogen to facilitate the replacement of two valves on the pipeline. On June 23, 2016 at 5:55 a.m. PT in Ventura, California, the pipeline operator began filling the pipeline with crude oil in preparation to restart normal operations. Shortly thereafter, a nearby resident called the emergency number on a pipeline marker located on the security fence around the perimeter of valve box 7002 to report the leak.

The operator’s control center responded by shutting-in the pipeline, activating the emergency response plan, and making appropriate agency notifications (NRC Number: 1151398).

Two technicians were dispatched to the site and confirmed the release of crude oil from an aboveground pipeline located inside an enclosed space (Figure 3). Personnel built an earthen berm/dam to prevent the crude oil from traveling any further or reaching the beach and/or Pacific Ocean, approximately a mile away. The Ventura Fire Department arrived on the scene and helped to add sand bags to the top of the dam built by the technicians.

Figure 3 Valve box 7002, source of the leak of crude oil. Photo provided by Operator.

The cause of the failure was due to an inadequate connection of flanges in valve box 7002. There was a visible gap between the flanges and the gasket. Three of the nuts on the underside of the flange were loose, and further investigation revealed that torque measurements were not adequate in several other flange nuts in the same valve box.

The examined gasket (Figure 4) had a fracture matching the edge of the raised faces of the flanges. Fine circumferential lines were present in the upper half of the gasket, but few or no such lines were observed near the bottom of the gasket.

The total volume of crude oil spilled was 1,075-barrels with a total property damage of $16,544,890. The operating pressure at the point and time of the accident was 260 psig (1,440 psig MOP). The downstream valve was closed remotely and the upstream valve manually. These two valves isolated 23,729 feet of the pipeline.

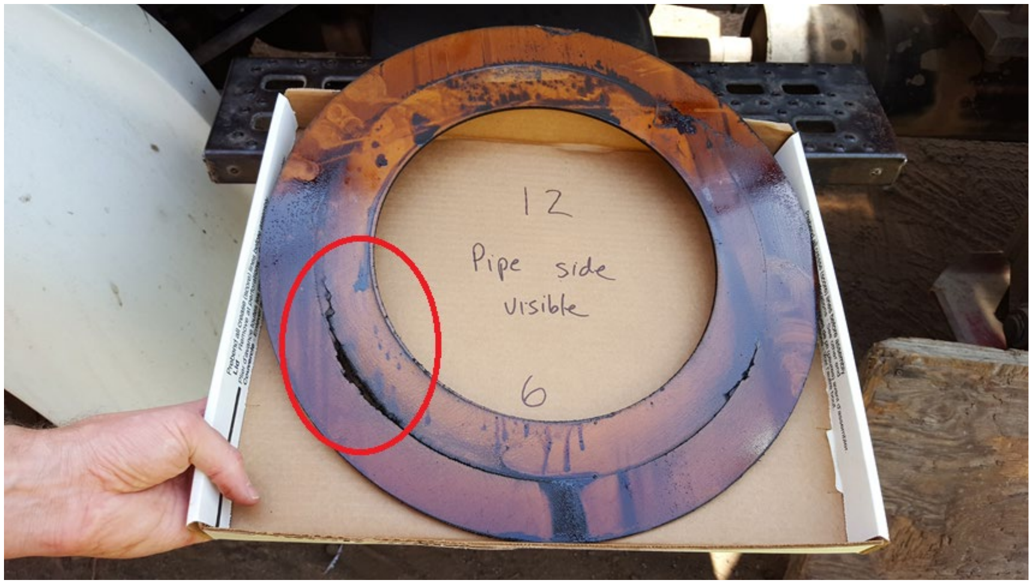

Figure 4 Removed gasket from the pipeline in valve box 7002. Photo provided by Operator.

Accident 5 – Alexander, ND – 03/20/2014 (475-barrels)
At approximately 5:00 a.m. CT on March 20, 2014 in Alexander, ND, the gasket on a flange valve riser located at an operator's station failed, resulting in a release of crude oil into the secondary containment structure. When the structure filled, some oil was released into the environment. The oil ran into a narrow (approximately ten-feet wide) path down a hill into a farmer's field, and into a dry, unnamed drainage. The operator estimated that approximately 475-barrels of crude oil were released, of which 375-barrels were recovered from the secondary containment structure. Approximately 100-barrels were released into the environment.

At approximately 6:18 a.m. CT, the operator contacted the environmental crew, which soon arrived on site and used absorbent materials and berms to stop further migration of the crude oil. Later that day, absorbent material began to remove contaminated soil from the dry drainage.

The operator's field personnel replaced the failed 8-inch Garlock gasket from between two ANSI 600 flanges with a Flexitallic CGI Style gasket, and torque was applied per manufacturer recommendations. Valves were properly aligned and the system was restarted at 5:30 p.m. CT. The gathering system was inspected to ensure that this issue was solved. Remediation of the contaminated soil continued until May 2, 2014.

This accident was reported to the NRC on March 31, 2014 after identifying this line to be jurisdictional and within a 1/4 mile of a high consequence area (HCA).

The facility is currently operated from a control center, which is manned 24/7. The control center, which was not operational at the time of the release, monitor pressure which have low and high pressure alarms, and flow meters that also have alarms. The control center can shut down the entire system. Field personnel are on-site during the day, and they check the assets periodically during the day. There are isolation valves upstream of the station, within the station, and downstream of the station. The field personnel can shut down local portions of the station, as they did when the release at issue was discovered.

The responsible contractor did not torque the bolts to specifications failing to adhere to proper procedures. A new contractor was hired to reconnect the flanges with new nuts, studs, insulating hardware and gasket. The torque targeting value was 515 ft-lb using the tightening sequence for a 16-bolt configuration flange.

The pressure at the point and time of the accident was 1,481 psig, with an MOP of 1,480 psig, exceeding MOP but not 110%. The total property damage accounted for $1,446,356, with almost 50% used for remediation of public property damage.

Accident 6 – Danville, Michigan – 04/13/2011 (9,000-barrels)

On April 13, 2011 at 6:58 p.m. ET, a pipeline operator received a call from a landowner indicating odors and a sheen in Bauer Drain in Dansville, Michigan. The operator made their initial NRC call at 9:55 p.m. ET.

The failure originated from a HL underground pipeline on the operator-controlled property and reached the water body Bauer Drain. The total volume of gasoline released was 9,000-barrels, with 1-barrel reaching Bauer Drain.

The gasket failed due to misalignment during construction in 2002. Figure 5 shows the failed flange assembly after digging operations, while Figure 6 shows the gasket (inside and outside) with signs of misalignment.

Figure 5 Failed flange assembly after digging operations. Photo provided by Operator.

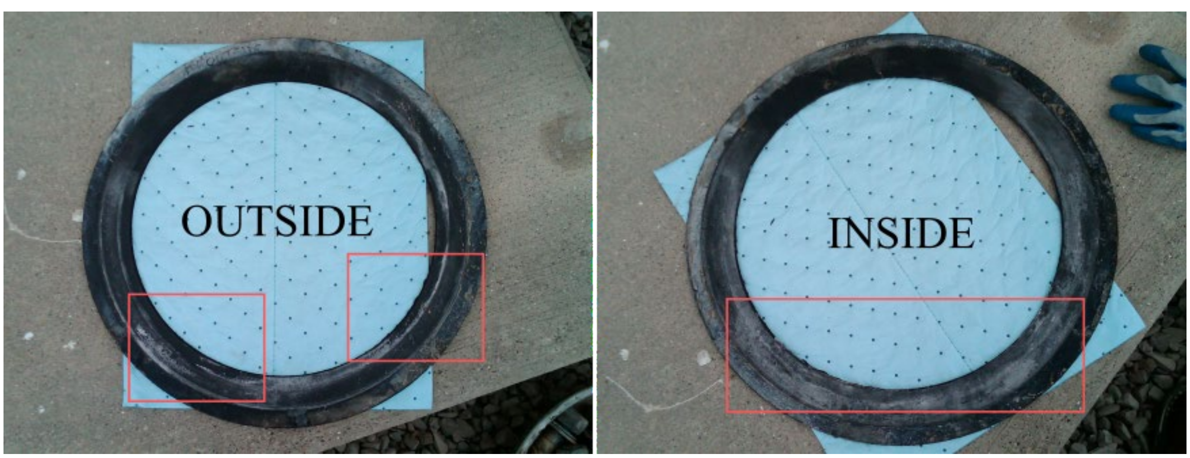

Figure 6 Outside and inside of gasket showing signs of excessive wear (red rectangle insets). Photo provided by Operator.

The pipeline was shut down for five days to make repairs. A boom was placed in Bauer Drain and recovery wells installed to collect free product. The operator removed 4,500 tons of non-hazardous impacted soils from this site.

The total costs were $35,728,903, with environmental remediation reaching $20 million and emergency response more than $14 million.

Regulatory Requirements for Flanges and Gaskets

Flanges are subject to design requirements under §192.143(a), 192.147(b), 195.102, 195.118(c), and 195.126. Not only flanges, but all components must be compatible and suitable for the service in which they are to be used. They must withstand operating pressures and other anticipated loadings without impairment of serviceability. Flange assemblies must withstand the maximum pressure at which the pipeline is to be operated, and maintain its physical and chemical properties at anticipated service temperatures.

For gas pipelines, standards Manufacturers Standardization Society (MSS) SP-44-2010, Standard Practice, "Steel Pipeline Flanges," and American Society of Mechanical Engineers (ASME) B16-5 -2003, "Pipe Flanges and Flanged Fittings," (incorporated by reference (IBR) in §192.7) cover specifications for steel pipeline flanges of different rating classes and nominal pipe size (NPS) requirements. These standards cover general considerations such as pressure-temperature ratings, component size, materials, dimensions, tolerances, marking, testing, chemical and mechanical properties, and definitions of other associated elements are described include bolting and gaskets. MSS SP-44 discusses manufacturing and inspection practices.

For hazardous liquid pipelines, MSS SP-44-2010, Standard Practice, "Steel Pipeline Flanges," 2010 edition and ASME B16.9-2007, "Factory-Made Wrought Buttwelding Fittings," December 7, 2007 (IBR §195.3). MSS SP-44 covers factory-made, seamless and electric welded carbon and low-alloy steel, butt-welding fittings for use in high pressure gas and oil transmission and distribution systems; including pipelines, compressor stations, metering and regulating stations, and mains. The Standard Practice governs dimensions, tolerances, ratings, testing, materials, chemical and tensile properties, heat treatment, notch toughness properties, manufacture, inspection, certification, and marking for high-strength, butt-welding fittings NPS 60 and smaller. Dimensional requirements for NPS 14 and smaller are provided by reference to ASME B16.9.

ASME 16.5 and ASME 16.9 are designed to be used in conjunction with other ASME standards. While not IBR in CFR 49 Parts 192 and 195, metallic gaskets for pipe flanges are covered in ASME B16.20, while non-metallic flat gaskets for pipe flanges are covered in standard ASME B16.21. Also, not IBR, bolts and stud bolts should be made of alloys that conform to standards ASTM A193, A320, A354, or A307, depending on pressure and temperature requirements. Materials should conform to standards ASTM A194 or A307 as it fits. Bolts, stud bolts, and nut threads should follow standard ASME B1.1 specifications. ASME B18.2.1 and B18.2.2 dictate dimensions of bolt square or hexagonal heads, and hexagonal nuts.

AID Recommendations for Inspectors

Based on lessons learned from accidents, AID recommends inspectors review operator's procedures, and construction and maintenance records to identify potential deficiencies and areas of improvement.

- Flanged connection elements vary in specifications depending on the application in the system. One of the most crucial variables to consider is the pressure-temperature rating, which will determine the proper class of flange, the type of gasket, and corresponding bolt-nut pair. Standard ASME B16.5 contains tables with specifications for these components.
- Procedures for specification of new and replaced flanges, gaskets, bolts, and nuts should be reviewed to ensure they appropriately consider:
  - Review of materials used in the system for compatibility to commodity and operating conditions
  - Review of gaskets for compatibility with flanges
  - Review of gaskets prior to in-line inspection
- Procedures for proper installation of new and replaced flange assemblies should be reviewed to ensure they appropriately consider:
  - Torqueing procedures for flanged joints
  - Bolts and stud bolts shall extend completely through the nuts without exceeding tightening torque recommended by gasket manufacturers
- Assess maintenance and operator qualifications records for tasks associated with flanged joints:
  - Identify the location of underground and aboveground flanges to characterize the environment of exposure
  - Support of flanged joints and potential sources of vibration
  - Methods of leak detection or monitoring. Active leaks from flanges or gaskets can go undetected for a long time due to small leak rates
  - Procedures to test effectiveness electrical isolation of flange isolation kits
  - Schedule of internal inspections of flanges
- Review previous accidents involving flanged joints and corrective actions established to avoid future releases.
  - Is the operator aware of the concerns surrounding flanges manufactured by Spanish company, ULMA Forja and its U.S. subsidiary, ULMA Piping that were not normalized to obtain proper mechanical properties such as toughness for cold operations and weather applications? Has the operator installed these flanges?
  - Were there failures related to the age of flanged joints?

- Review operator's risk assessment program elements associated with buried flanges. If pipeline assets have this as an identified risk element, these programs should evaluate the original condition of the asset construction, gasket failure prevention and maintenance, and hydrotest conditions.

Appendices in this Bulletin includes the following supplemental information:

- **Appendix A – Flange Assembly Technical Information**
- **Appendix B – Data Analysis**
- **Appendix C - Detailed Summary of Accident Investigation Findings**
- **Appendix D – References**

Appendix A – Flange Assembly Technical Information

A flange assembly consists of flanges, gasket(s), and bolts. Flange assemblies are used to mechanically connect pumps, meters, regulators, valves, pipe, and other appurtenances in a pipeline system. An advantage of the use of flanges over welded connections is the easy access to the connected appurtenance for cleaning, inspecting or conducting modifications. Flanges can be welded or screwed. Flanged joints provide a seal by bolting two flanges or a flange on either side of an appurtenance with a gasket between them. The use of flanges on underground pipelines is allowed, but it is not regarded as the best practice.

Flanges

Flange Types

The most used flange types in a hazardous liquid pipeline system are welding neck, blind, threaded, slip-on, lap-joint, and socket weld. A diagram for each type of flange can be seen in Figure 7. Flanges have two facings: raised face and flat face.

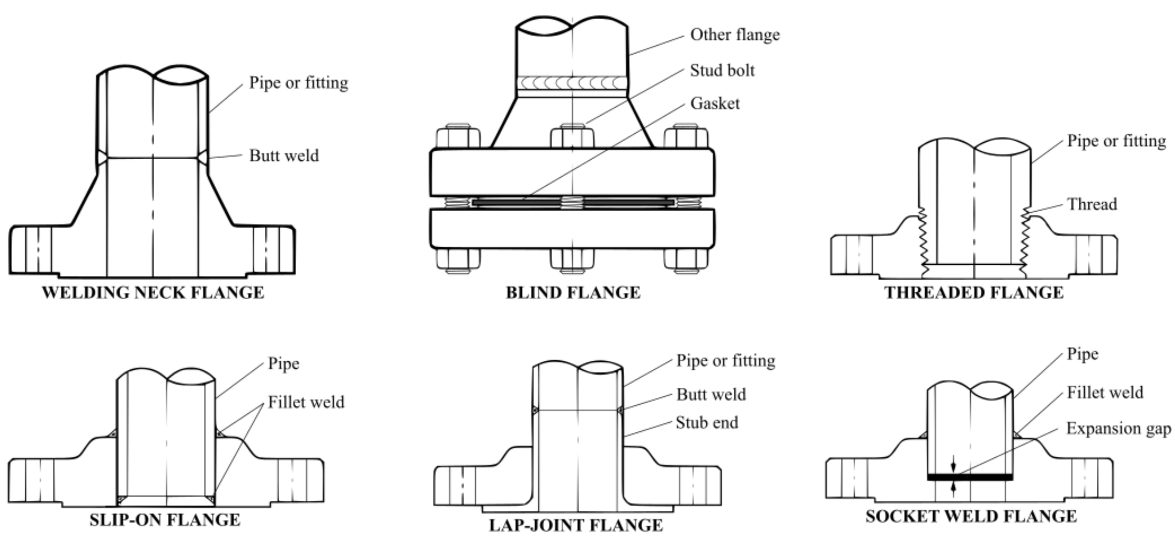

Figure 7 Most common types of flanges in a pipeline system. Adapted from ASME B16.5-2017

Welding neck flanges are used in high pressure environments, where the neck of the flange is welded to the pipe. The stress concentration in the base of the hub is reduced by transferring it from the flange to the pipe.

Blind flanges are used to seal the end of a piping system, valves, and pressure vessels to prevent flow. They are suitable for high pressure-temperature applications (i.e. pressure testing, easy access to a pipe segment, etc.).

Threaded flanges have a female thread and is screwed on a male threaded pipe without being welded. This type is often used for small pipe diameter and high pressure requirements.

Slip-on flanges slide over the pipe and are secured with a fillet weld inside and outside to increase strength of the fitting and prevent leakage.

Lap-joint flanges are used in combination with a lap joint stub end. These flanges fit over the pipe and are welded to the stub end allowing the lap joint to rotate. This configuration permits the system to avoid any issues with bolt hole alignment.

Socket-weld flanges are connected by slipping the pipe into the socket and applying a fillet weld on the outside of the flange. The benefits of this is to allow a smooth bore and better flow of the commodity inside the pipe. This type of flange is used for small pipe sizes and low-pressure applications.

Spectacle blind flanges are specialized flanges used between two standard flanges in lieu of blind flanges, designed to block off a section of pipe. These flanges are also referred in Figure 7 as blind flanges. It consists of two metal discs attached to each other in the middle by a small metal section. One end has an opening to allow flow through the pipe, while the other end is solid to block flow during maintenance.

Flange Material

Although pipe flanges are manufactured in different materials such as stainless steel, aluminum, brass, plastic, and others, the most used material is carbon steel with machine surfaces. Depending on the application, flanges could be designed to contain coated internal layers or machined to a specific finished surface.

Flange face is the type of surface area of the flange that accommodates the sealing gasket:

- Flat Face: the flange surface is flat and uses a full-face gasket in low pressure applications to connect pipes with cast equipment.
- Raised face: The gasket surface area is above the bolting line of the flange. They concentrate the stress and the sealing in a smaller portion of the flange face for stronger connections.
- Ring joint: used in metal-to-metal flanged joints. A ring joint gasket is squeezed inside the circular grooves of the flanges for very tight connection.

Flange finish is the type of roughness on the flange face to ensure the gasket adheres to the flange so product cannot leak. A stock finish is the most used finish in the oil and gas industry.

Flange Rating

Steel pipeline flanges are categorized in classes, a combination of pressure-temperature ratings that define maximum allowable working gauge pressure. The seven classes are 150, 300, 400, 600, 900, 1500, and 2500. As the rating increases, the flange weight increases and it can withstand higher pressures and temperatures. However, the rating is not directly proportional when it makes reference to an increase of temperature. These ratings vary by material being used to manufacture these components.

Insulating flanges prevent the flow of an electric current between the two pipes or appurtenances being connected. Flange insulation kits typically contain a gasket, washers, and sleeves for the bolts to increase the effectiveness of cathodic protection systems, and control losses due to corrosion and stray electric currents in piping.

Proper installation and maintenance of flanges and corresponding accessories critical to the safe operation of pipeline facilities. Flange surfaces should be clean and smooth, and sealing faces should be connected parallel to each other

Gaskets

A gasket is a mechanical device to seal flanges. A gasket fills the spaces and irregularities between two mating flanges to prevent the product from releasing. Gaskets are required to withstand operational pressures and temperatures of the pipeline system while providing chemical resistance to prevent any unintentional reaction with the fluid in the pipeline system. Gaskets are selected based on the product being transported, the operating temperature and pressure, any fugitive emissions requirements, and mechanical considerations (vibration and oscillation of the piping system).

Gasket Types

Gaskets are classified by material type: nonmetallic, metallic, and composite.

The selection of gasket materials shall be suitable for the service condition. They shall withstand the expected bolt loading without damaging the gasket. Special attention should be given when hydrostatic tests and in-line inspections are performed on the pipeline system because pressure or material specifications can be mistakenly exceeded. The characteristics of these materials include density, flexibility, compatibility with the fluid being contained, and gasket compression needed to maintain sealing. Gasket materials are classified by group to meet flange class and bolting strength criteria.

Gasket Configuration

Gasket configurations range from full face, inner bolt circle (IBC), and metal ring type joint (RTJ) gaskets. Figure 8 shows a diagram for each of these configurations.

- Full face gaskets cover the surface area of the flange and include bolt holes, they can only be used with full face flanges.
- IBC gaskets are typically used on raised face flanges, where more pressure is concentrated on the smaller gasket area, increasing pressure capabilities.
- RTJ gaskets are metal oval or octagonal rings designed to fit on the corresponding groove, usually made of soft iron or stainless steel, suitable for very high pressure and temperature applications.

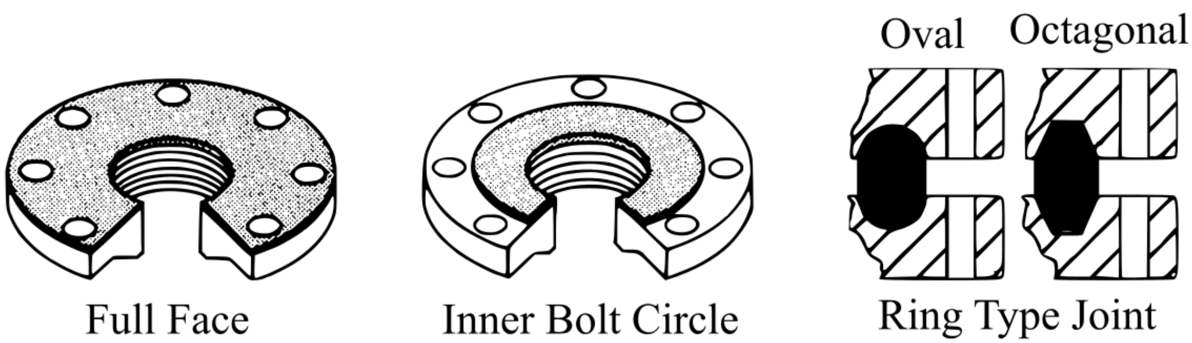

Figure 8. Typical gasket configurations used in pipeline systems. Adapted from ASME B16.5-2017

Bolts and Stud Bolts

Bolts and stud bolts (Figure 9) are used in combination with flanges and gaskets to ensure proper sealing of components to avoid any potential leaks at these intersections. Bolts and stud bolts must extend completely through the nuts. Bolting and nuts specifications must conform to standards listed in Table 1.

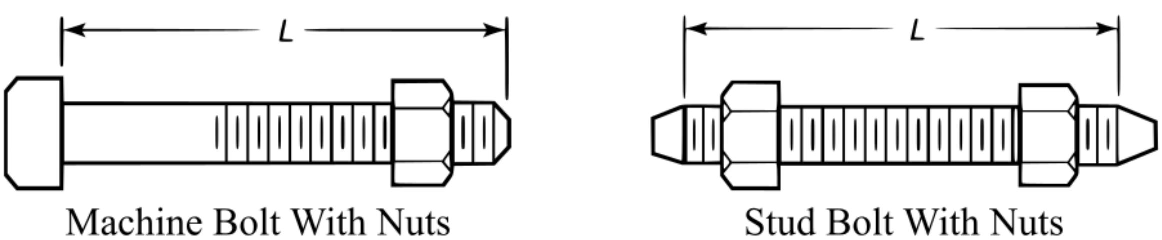

Figure 9. Bolts and stud bolts used in conjunction with flanges and gaskets. Adapted from ASME B16.5-2017

The bolting method for tightening flange bolts may involve the use of torque wrenches or hydraulic stud tensioners. Bolt holes in a flange are in multiples of four, which they shall be equally spaced, and pairs of bolt holes shall straddle fitting centerlines. The proper torque values are based on different component characteristics, such as gasket material, flange size, flange type, bolt material, lubricant, etc. Torque values from gasket manufacturing recommendations must be followed if they are available.

The amount of torque should be applied evenly involving several steps. Methods vary and number of steps must be defined by operator procedures and recommendations of the gasket manufacturer. Figure10 shows an example of sequences for tightening bolts across a flange.

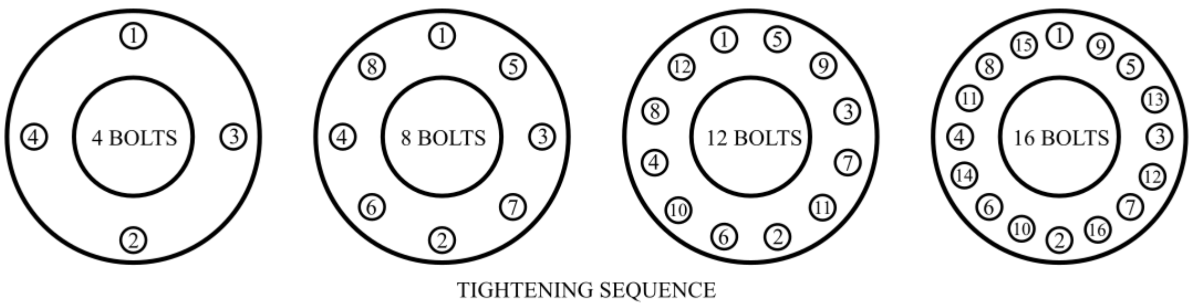

Figure 10. Tightening sequence of bolts across a flange.

Required standards and their applications on a flanged assembly are shown in Table 1.

Table 1. Standards related to flange assemblies and their application to each component.

	Standard	**Application**
IBR Part 192	MSS SP-44-2010, Standard Practice, “Steel Pipeline Flanges,” 2010 edition	Tables incorporate specifications for steel pipeline flanges by covering different rating classes and nominal pipe size (NPS) requirements. These standards cover general considerations such as pressure-temperature ratings, component size, materials, dimensions, tolerances, marking, testing, chemical and mechanical properties, and definitions of other associated elements are described including bolting and gaskets. MSS SP-44 discusses manufacturing and inspection practices.

	ASME B16.5-2003, "Pipe Flanges and Flanged Fittings," October 2004	Covers pressure-temperature ratings, materials, dimensions, tolerances, marking, testing, and methods of designating openings for pipe flanges and flanged fittings. B16.5 is limited to flanges and flanged fittings made from cast or forged materials, and blind flanges and certain reducing flanges made from cast, forged, or plate materials. This Standard also included requirements and recommendations regarding flange bolting, flange gaskets, and flange joints. This Standard is to be used in conjunction with equipment described in other volumes of the ASME B16 Series of Standards as well as with other ASME standards, such as the Boiler and Pressure Vessel Code and the B31 Piping Codes. Note: Table 1B Bolting specifications, Table B-1 Classification of gaskets by material type
IBR Part 195	MSS SP-75-2008 Standard Practice, "Specification for High-Test, Wrought, Butt-Welding Fittings," 2008 edition	Covers factory-made, seamless and electric welded carbon and low-alloy steel, butt-welding fittings for use in high pressure gas and oil transmission and distribution systems; including pipelines, compressor stations, metering and regulating stations, and mains. This Standard Practice governs dimensions, tolerances, ratings, testing, materials, chemical and tensile properties, heat treatment, notch toughness properties, manufacture, inspection, certification, and marking for high-strength, butt-welding fittings NPS 60 and smaller. Dimensional requirements for NPS 14 and smaller are provided by reference to ASME B16.9.
	ASME B16.9-2007, "Factory-Made Wrought Buttwelding Fittings," December 7, 2007	Standard covers overall dimensions, tolerances, ratings, testing, and markings for factory-made wrought buttwelding fittings in sizes NPS 1/2 through NPS 48 (DN 15 through DN 1200). It covers fittings of any producible wall thickness. This standard does not cover low pressure corrosion resistant buttwelding fittings. See MSS SP-43, Wrought Stainless Steel Butt-Welding Fittings. This Standard is to be used in conjunction with equipment described in other volumes

		of the ASME B16 Series of Standards as well as with other ASME standards, such as the Boiler and Pressure Vessel Code and the B31 Piping Codes.
Informative but not IBR	ASTM A193[4]	High-strength bolting specifications
	ASME B16.20[5]	Metallic gaskets for pipe flanges. Ring joint gasket dimensions
	ASME B16.21[6]	Non-metallic flat gaskets for pipe flanges
	ASTM A193, A320[7], A354[8], A307[9]	Specification of alloys for bolts and stud bolts
	ASTM A194[10], A307	Material for nuts as it fits each standard
	ASME B1.1[11]	Bolts, stud bolts and nut threads specifications
	ASME B18.2.1[12], B18.2.2[13]	Dimensions of bolt square or hexagonal heads, and hexagonal nuts.

[4] ASTM A193 - Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications.
[5] The American Society of Mechanical Engineers (ASME) B16.20-2017 - Metallic Gaskets for Pipe Flanges.
[6] The American Society of Mechanical Engineers (ASME) B16.21-2016 - Nonmetallic Flat Gaskets for Pipe Flanges.
[7] ASTM A320 - Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service.
[8] ASTM A354 - Standard Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners.
[9] ASTM A307 - Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60 000 PSI Tensile Strength.
[10] ASTM A194 - Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both.
[11] ASME B1.1 - Unified Inch Screw Threads, UN and UNR Thread Form.
[12] ASME B18.2.1 - Square, Hex, Heavy Hex, and Askew Head Bolts and Hex.
[13] ASME B18.2.2 - Nuts for General Applications: Machine Screw Nuts, Hex, Square, Hex Flange, and Coupling Nuts (Inch Series).

Appendix B – Data Analysis

Data Analysis of Flange and Gasket Failures

AID conducts comprehensive data analysis to identify national pipeline incident trends or novel causes. Understanding the consequence of these accidents offers insight in areas for potential improvement to reduce risk and improve integrity management.

The PHMSA Accident Investigation Division (AID) analyzed accident information from hazardous liquid reportable accidents from 2010 to Present. Flange assembly failures were identified as "Flange" under Part C: Additional Facility Information, Numeral 3: Item Involved in Accident in Form PHMSA F 7000-1. Although failures are listed as flange, they do not necessarily indicate a failed flange, the failure is likely to be related to a gasket failure or incorrect bolt torque.

During the last ten years, 219 of the 4079 (5%) hazardous liquid accidents occurred where the 'item involved in the accident' was a flange. Flange assembly failures accounted for a total property damage of $93,807,768 and 26,800-barrels of unintentionally released hazardous liquid product, which about half was released outside the operator's property. There were no fatalities or injuries associated with these failures. Of the 219 flange assembly failures, in 159 (72%) accidents, the quantity unintentionally released was five barrels or less. Eight accidents resulted in major releases of more than 500-barrels.

The most common cause of flange failures is associated with Equipment Failure, which accounts for 126 or 58% of the 219 accidents and $70,000,000 or 75% of the total property damage. The most predominant equipment failure sub-cause is Non-Threaded Connection Failure (107 or 49%). Incorrect Operation follows with 73 or 33% of the 219 accidents and $5,000,000 or 6% of the total property damage. The most predominant incorrect operation sub-cause is Equipment Not Installed Properly (34 or 16%). Table 2 is a detailed breakout of the cause and sub-cause as categorized on Form PHMSA F 7000-1 of the 219 flange assembly failures.

Table 2. Total property damage and number of accidents due to failure of flange assemblies from 2010 to Present.

Cause/Sub-Cause	Number of Accidents	Total Property Damage
EQUIPMENT FAILURE	126	$70,139,691
Non-Threaded Connection Failure	107	$55,569,523
Other Equipment Failure	9	$11,690,025
Defective or Loose Tubing or Fitting	4	$417,325
Threaded Connection/Coupling Failure	2	$1,118,600
Failure of Equipment Body (Except Pump), Tank Plate, or Other Material	2	$49,115
Pump or Pump-Related Equipment	1	$1,200,003
Malfunction of Control/Relief Equipment	1	$95,100
INCORRECT OPERATION	73	$5,287,332
Equipment Not Installed Properly	34	$2,415,823
Other Incorrect Operation	18	$1,550,920
Pipeline or Equipment Overpressure	12	$1,138,596
Valve Left or Placed in Wrong Position, But Not Resulting in a Tank, Vessel, or Sump/Separator Overflow or Facility Overpressure	5	$23,305
Damage by Operator or Operator's Contractor Not Related to Excavation and Not Due to Motorized Vehicle/Equipment Damage	2	$114,558
Wrong Equipment Specified or Installed	1	$33,400
Tank, Vessel, Or Sump/Separator Allowed or Caused to Overfill or Overflow	1	$10,730
OTHER INCIDENT CAUSE	8	$17,346,654
Unknown	4	$17,126,999
Miscellaneous	4	$219,655
NATURAL FORCE DAMAGE	7	$824,883
Temperature	5	$130,649
Earth Movement, Not Due to Heavy Rains/Floods	1	$627,734
Other Natural Force Damage	1	$66,500
CORROSION FAILURE	3	$132,183
Internal Corrosion	3	$132,183
OTHER OUTSIDE FORCE DAMAGE	2	$77,025
Other Outside Force Damage	2	$77,025
TOTAL	219	$93,807,768

Most accidents occurred aboveground (142), which represents 65% of the 219, while 21% happened underground, and 14% are associated with tanks and transition areas. During the 10-year period, there were 81 flange assembly accidents due to gasket failures, 34 to equipment not installed properly, 26 to seals and O-rings, 18 to incorrect operation, 12 to overpressure activities, and 17 to events leading to the failure of any of the flange assembly components (i.e. damages due to construction practices, temperature, impact, faulty valve operation, defective or loose fittings, internal corrosion, earth movement, etc.)

Table 3 shows a breakdown of the total property damage and barrels spilled per year. Results from this analysis indicate the influence of outliers such as the release of 9,000-barrels of gasoline with costs over $35,000,000 in Dansville, Michigan in 2011. In 2016, a crude oil release of 1,075-barrels in Ventura, California had costs of more than $16,000,000. And a third outlier was the failure in Everton, Missouri in 2017 where 450-barrels of crude oil were released and costs reached more than $11,000,000.

Table 3. Total cost and total barrels spilled per year.

Year	Number of Accidents	Property Damage	Barrels Spilled
2010	9	$1,086,402	1,865
2011	16	$42,510,608	11,114
2012	19	$4,814,536	2,195
2013	22	$2,589,797	400
2014	22	$1,786,405	741
2015	27	$1,572,296	3,600
2016	30	$18,248,829	1,357
2017	16	$13,698,287	2,348
2018	31	$3,317,297	243
2019	23	$3,629,229	929
2020	4	$554,082	2,008
Total	219	$93,807,768	26,800

Figure 11 shows the accident history by year in terms of total accidents, except for 2020 where the number of accidents is 4. The highest number of accidents during the 10-year period occurred in 2018 and 2016 with 31 and 30 respectively, which is 45% and 41% higher than the overall mean. The average for the 10-year period is 22 accidents per year.

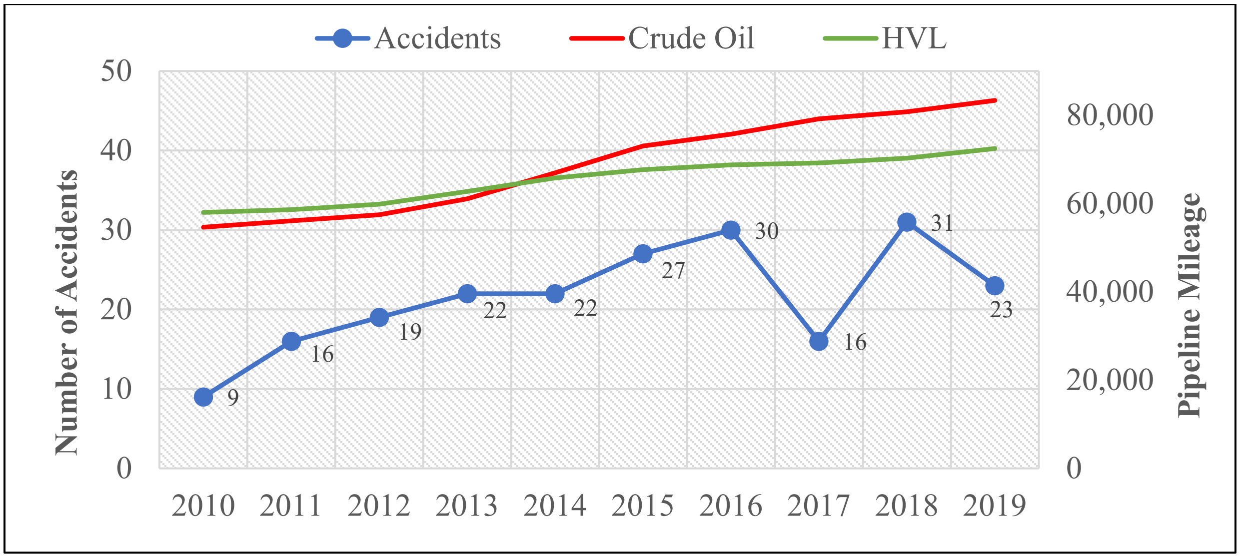

Figure 11. Total number of accidents per year and trends of miles of crude oil and HVL pipeline from 2010 to 2019.

The trend of accidents from 2010 to 2016 increased more than three times. AID found a strong correlation of miles of crude oil and highly volatile liquids (HVL) pipeline (interstate and intrastate) and the number of accidents. In the last ten years, the number of pipeline mileage in the continental U.S. increased 53% for crude oil and 25% for HVL. Other factors can also play a role on this trend of accidents such as infrastructure aging, reporting criteria, regulations, and establishment of integrity and mitigation programs.

The total property damage for each cause-type is shown in Table 4. Accidents due to Equipment Failure are the most prevalent, accounting for 58% of the total number of accidents in the 10-year period, followed by Incorrect Operation with 33% of the total number of accidents. The four most frequent sub-causes are Non-Threaded Connection Failure (107), Equipment not installed properly (34), Other Incorrect Operation (18), and Pipeline or Equipment Overpressure (12).

Appendix C - Detailed Summary of Accident Investigation Findings

AID performed an in-depth review of the accident report narratives to provide inspectors with actionable information about the cause of flange assembly failures. AID found that the predominant failure cause of flange assembly failures was detrimental stress on the flange assembly. The foremost cause of the stress was incorrect torqueing of bolts (over compression, uneven torqueing, inadequate torqueing, incorrect sequence of bolting). Other causes of stress on the flange assembly was due to thermal overpressure, overburden, misalignment of flanges, pipeline settlement, inadequate pipe support, overpressure, bending, and vibration. Additionally, failures were due to incorrect gasket specification, damage related to hydrostatic pressure testing and in-line inspection tools, and incorrect installation/operation. Some of the incorrect operations occurred during simultaneous operations. In rare occasions, the flange, gasket, or bolt experienced a material failure. Flange and bolt material failures were mostly due to corrosion and gasket failures were typically due to incorrect specification. After close evaluation of each of the flange assembly accidents, the apparent causes for flange assembly failures are categorized and summarized below.

Flange (5) and Bolt (2) Material Failures

Of the 219 flange assembly failures, only 7 were attributed to material failure of the flange or bolt. Four of the seven were due to corrosion. Gasket material failures were most often due to incorrect specification.

Flange Failures

- A section of piping and the internal surface of the discharge flange weld of the pump station contained a pinhole leak due to microbiologically induced corrosion.
- A flange assembly on a dead leg manifold leaked due to internal corrosion. The operator had an on-going awareness of potential dead leg sources and worked toward eliminate areas that may cause a potential leak.
- A weld neck flange on the water draw connection on a tank leaked due to internal corrosion.
- A flange on a tank’s water draw valve cracked due to accumulated water between the flanges.
- Circumferential crack in the flange neck adjacent to a girth weld located on the upstream side of a mainline valve.
- A buried 30-inch flange situated on the compressed natural gas suction header was the source of the release leaked due to damage (gouge) to the flange face. The damage was caused by impact during initial construction.

<u>Bolt Failures</u>

- The bottom of the bolt/nut sheared due to hydrogen stress cracking. The grade of the bolts was unsuitable for buried service under cathodic protection.
- The section of pipe was under thermal stress from contraction and expansions due to seasonal temperature changes. Some bolt surface corrosion caused the flange to splay open and the gasket to fail. The entire header was replaced to mitigate the stresses.

<u>Gasket Failures - Incorrect Specification</u>

- The operator replaced defective gaskets with compressed fiber gaskets: glass-reinforced epoxy (GRE) laminate bonded to a metal core.
- Operations reported a leak of 10-barrels of crude oil from one of the connecting above ground flanges of new terminal piping that was in the process of being commissioned. The tank and manifold valve used for the commissioning were isolated and the leak was stopped. The cause of the leak was determined to be a gasket of incorrect thickness that was used in the flanged connection. The gasket was replaced with the correct type. Flange re-torqued and line re-started.
- A gasket for an ANSI 300 flange was installed on an ANSI 150 flange. The mismatched bolt holes were forced to fit and tightened to seal. Over time, the gasket cracked and began leaking.
- The type of gasket installed had no secondary sealing surface and was made of non-compressible material. The gasket was a phenolic material used for electrical isolation. The gasket was replaced with on suitable for this type of pipeline services.
- The gasket connecting the valve to the pipe was found to not be currently approved design for joining two flange types.
- Replaced a failed Garlock gasket with a Flexitallic CGI gasket so they could properly torque and align all the valves. (2 accidents)
- A slip blind used to seal off a tank isolation valve was installed with a used gasket. The used gasket did not allow for a proper seal.

<u>Gasket Failures – Other</u>

- Removed defective corrugated gasket and replaced with Flexitallic gasket.
- A failed fiber gasket on the suction side of the booster pump caused the release of 10-gallons of crude oil due to normal wear. The gasket was replaced and resurfaced. A preventative action for the future included a scheduled inspection of all booster suction flanges at the station.
- There were fifteen failed cathodic protection insulating gaskets.
- To prevent future accidents, a good practice is to inspect gaskets prior to installation to ensure manufacturing defects are not present.

Failures Related to Hydrostatically Testing

- Crude oil released from a flanged connection. The cause analysis of the failure determined that during a hydrostatic pressure test, the bolts assembly was not torqued to specification. The gasket was replaced and the flange bolts torqued to specification. Corrective actions included revision of torqueing procedures with contractor personnel.
- A blind flange, added to isolate a section of piping from the manifold, had trapped water left from the hydrotest. Due to cold temperatures, the water froze and thermal stresses caused the flange assembly to leak.
- A product movement was made from a tank through an existing pump. The movement pressured up the section of piping on the active side of a gate valve. Cold temperatures along with water accumulation in the gate valve resulted in ice formation in the valve body which allowed product to bypass the vale into the assets under-construction. Product release was observed at the pump's suction and discharge valves. Future preventative actions include ensuring lockout/tagout are followed, installing barriers to separate active assets from under construction assets, and properly dewatering after hydrostatic pressure testing and performing winterization tasks.
- Petroleum product was discovered in a monitoring well, but the source of the leak was not found until a month later with a hydrotest. The tank line was evacuated and excavated. Five buried flanges were the cause of the release. The original construction took place 80 years before the accident by an unknown operator, who failed to bag or vault the flanges. Corrective actions included cutting out flanges and replacing them with a spool of pipe and adopting this practice in the future for identified flanges through excavation. To avoid further reoccurrence, the operator has opted for not employing and removing underground flanges.
- While reinstalling a 4-inch gate valve that was removed for a hydrostatic pressure test, the valve flange and the pipe flanged arced. The residual NGL vapors ignited and caused a flash fire.
- An operator implemented a review of all hydrostatic pressure testing plans to ensure measures are in place to displace and dry facility lines following hydrotesting and conduction field review to determine optimal locations of isolating new construction prior to commissioning.

Failures Related to In-line Inspection

- Spiral wound gasket pulled from the pipe and leaked after a sizing tool run. Several rounds of the spiral were missing. A new gasket was installed with a reinforced inner ring to prevent recurrence.
- A valve flange assembly leaked natural gas liquids (NGL) when an inspection tool arrived during a tracking operation. The gasket was replaced and the leak stopped.

- A gasket failed immediately following the shipment through a valve after a corrosion detection pig (CDP) smart pig tool run. CDP is a high-resolution magnetic flux leakage (MFL) inspection tool.
- A pipeline integrity management (PIM) tool passed through a block valve cause a gasket failure resulting in a release of propane vapors. A bolt on clamp was installed, securing the release.

Failures Due to Stress on the Flange Assembly

Thermal stress (19 accidents) - Accidents occurred when there were thermal changes to isolated sections of pipe without thermal relief. Some of these were related to incorrect operations.

- 15-gallons of distillate released from a tank due to a separation of a flange with a drop of temperature, which increased thermal stress on the bolts that caused the flange to separate.
- The section of pipe was thermally pressured without relief and deformed the temporary slip blind which led the gasket to fail. Operations did not recognize a thermal relief had been open to the isolated segment of pipe with the slip blind.
- The inlet piping exceeded its MOP due to thermal expansion. A thermal relief valve was installed to prevent re-occurrence.
- A valve that was normally open to allow for thermal expansion was closed during maintenance work for isolation purposes. Upon completion of the work the valve was not re-secured in the open position. This resulted in thermal pressure build up in an isolated section of terminal piping and caused the gasket to leak.
- The section of pipe where the release occurred was blocked in by three closed valves and did not have a thermal relief valve installed. The line was not running at the time of the release due to completing a shipment several days before.
- The leak was from a flange on a local recirculation pump. It was determined to be caused by thermal pressure build up due to a valve being closed.
- A valve was inadvertently left in the closed position which isolated a section of pipe, allowing thermal pressure to build and caused a gasket to fail. The release was found shortly after starting up a delivery. A thermal relief valve was added.
- An employee was assigned to monitor the pressure on an isolated piping section during a station outage. The employee monitored the pressure every half hour but failed to open a 2” valve on the manifold headers that would expose the pressure gauges to ambient pressure as he did not understand that the valves below the pressure gauge need to be opened. The high temperatures during the afternoon caused a thermal pressure buildup which resulted in a failed gasket between the manifold pipe and the tank valve.

- A station had been out of service for 2 months while the operator was making modifications to station piping. A valve that had been closed downstream of the tank valve had been closed which created a 25-foot section of piping without thermal relief.
- Thermal relief valve failed to relieve at the correct pressure. The valve was replaced.

Actions operators took to prevent recurrence:

- Install thermal reliefs on isolated sections
- Include a plan to provide thermal relief on all hot work permits.

<u>Lack of Pipe Support</u> - 1.5-barrels of crude oil leaked from an underground flange connection. The lack of proper support may have been a key contributing factor in the loosening of the flange bolts which ultimately led to the release. The flanged connection was excavated, proper supporting fill material was installed in the ditch and the flange was re-torqued. The line was refilled, pressurized and checked for leakage.

<u>Vibration</u> – Failure analysis revealed the cause to be vibrational self-loosening over time of the flange bolts on a 2” branch drain connection.

<u>Bending Stress</u> - The electrical isolation joint (EIJ) used a double sealing gasket set and epoxy sealant to prevent leakage at the joint interface. Failure analysis concluded that the epoxy seal was compromised (missing and cracking consistent with excessive bending stress) at the location of the release along with protruding (unsupported) inner and outer gasket had broken (consistent with a progressive cracking mechanism such as fatigue). The break was likely driven by uneven loading due to bending stresses. The sealant recoiled into the cavity allowing product to escape.

<u>Incorrect Torqueing of Bolts</u>

Often the accident narratives do not include sufficient information to determine if the leak was caused due to gasket failure or because the bolts were not correctly torqued.

- Under routine rounds, a technician discovered a leak of gasoline (11-gallons) from an aboveground valve flange and placed a bucket underneath to catch the commodity and avoid further contamination. The maintenance crew re-torque the bolts on the flange to stop the leak by reducing the flow without shutting down the pipeline. The failure was caused by inadequate torqueing of bolts. As a best practice, the pump was scheduled for a gasket replacement during the next shutdown.
- Inadequate bolting led to the spill of 17-gallons of oil from a cork gasket in a valve setting. The gasket was found to be pinched at the point of the leak, indicating over tightening of stud bolts during installation.

- Two barrels of crude oil were discovered on a tank pad area by technicians at the terminal. Control center shut down the tank line to allow for maintenance personnel to control and find the release. The source of the release was a buried flange on the tank line piping. The bolts on the flange were re-torque and pipeline was restarted. The leak was monitored to confirm the repair.
- Approximately 40-barrels of gasoline were released from a flanged connection associated with a valve on an aboveground atmospheric storage tank. The release occurred two weeks after a tank inspection and valve installation by operator's personnel. All the product was contained inside the tank dike. Personnel involved with the release was requalified for this task due to failure to follow procedures correctly.

Actions operators took to prevent recurrence due to incorrect torque:

- Require torqueing tasks to be completed without interruption. If interrupted, re-initiate from the beginning. Require torqueing procedures to have signatures of the person performing the torqueing and the inspector on site.
- After commissioning, maintenance, or other operations that changes the pressure around the valves, ensure proper torque and monitor the flanges for leaks.

<u>Flange misalignment</u> - Two 12-inch crude oil lines were being filled when the flanges on the existing meter skid began to leak. Investigation found that the flanges were misaligned causing the 12-inch gasket to crack at the top. New bolts and gaskets were installed and pipeline returned to operation.

Failures Due to Incorrect Installation/Operations

- An incident occurred due to a missing gasket and another incident occurred when a blind flange was not installed when required.
- Contractor was using an electric impact wrench to unbolt a flange. When the flange separated, NGL vapor released, the electric impact caused ignition causing a small flash fire. Spark producing, electric impact wrenches were no longer permitted.
- After installing two new valves, the operator removed slip blinds that were used to isolate a new section of a header. The flag on the newly installed valve signaled it was closed (later determined that the valve had not seated properly so was open). The flange was being reconnected when the contractor applied nitrogen to perform the pressure test. Residual product pushed through the unseated valve and into the header where the slip blind had been removed. The operator revised the procedure to require a fully closed system prior to pressure testing any installation.

- During installation of a slip blind, there was difficulty getting the flanges to spread and line back up. The space between the flanges was not large enough to insert a ¾ skillet and two Flexitallic gaskets. Uneven pressure was placed on one other gaskets before it was bolted resulting in uneven/over compression of sections of the gasket. The gasket failed when pipeline pressure was restored.

<u>Failures Due to Operator Error During Simultaneous Operations</u>

- A flash fire occurred at a pump station while personnel were welding a flange on a pump header during simultaneous construction and maintenance work. Although the station had been air gapped, nitrogen purged, and left open to the atmosphere for over 24 hours prior to welding, gas released from unrelated, nearby valve maintenance. Because of the incident, the operator re-emphasized the hazards of simultaneous work. After the accident, the operator re-emphasized the hazards of simultaneous work and reviewed future work activities to better manage the hazards associated with them.
- The operators were performing work to remove mainline pig traps, replace valve settings and disconnect a 6-inch propane line cross-over in conjunction with a hydrostatic pressure test of a lateral. The pipeline was shut down, product displaced with nitrogen, depressurized and isolated. Atmospheric monitoring indicated 0% lower explosive limit (LEL) inside the piping. A flash fire occurred when workers unbolted a flange to remove a slip blind because another worker was performing a separate work task using an acetylene torch to cut adjacent piping 5-feet away. A small amount of product released from behind the slip blind when the last two bolts of the flange were removed. The workers did not recognize the hazard of potential trapped gas between a slip blind bolted to a valve. Prior to the job beginning, Operations determined that a new blind flange should have been tapped with a vent to relieve any pressure if the blind flange had to be removed.
- During a routine equipment check, a technician opened a tank valve. A contractor working on the line downstream of the tank valve had a flange unbolted. When the technician opened the valve, product flowed to through the unbolted flange.
- While receiving a gasoline delivery through a manifold at a terminal, maintenance workers were performing a maintenance task to rotate a valve gear box and install an extension handle on the manifold. During the maintenance task, the bolts that secure the gear box to the valve body where removed and the gear box was raised to allow it to be rotated. When the gear box was raised, a slamming sound was heard and within a few seconds, two flanges on other valves in the manifold released a spray of gasoline and the gasoline vapors ignited. The manifold piping was isolated from the remainder of the facility pipeline by closing the valves and later by installing blinds in the lines. The investigation determined that the internal valve plate

slammed closed against the inbound delivery when the gear box was lifted off the valve pinion. The root cause was employees failed to follow the established practice of communicating with operations before and after a job and to only work on inactive piping.

Operators implemented the following actions to prevent recurrence of accidents caused by operator error:

- Require field personnel to remain on site after any maintenance activity when introducing pressure to the system.
- Include secondary verification of checks and balances on critical processes.
- Monitor tank commissioning by maintenance technician until roof has floated. Periodically inspect during the filling process including the bolts on all tank appurtenances. Perform a final inspection when filling process is complete including verifying the bolt torque.
- Install monitoring wells on all block valves. Perform a leak survey of the block valves and confirm that there is no systemic issue with insulating kits.

Appendix D - References

1. Code of Federal Regulations (CFR) Title 49, Subtitle B, Chapter I, Subchapter D, Part 195, Subpart C, §195.126.
2. ASME B31.4-2019 – Pipeline Transportation Systems for Liquids and Slurries
3. MSS SP-44-2016 - Steel Pipeline Flanges.
4. MSS SP-75-2008 Standard Practice, Specification for High-Test, Wrought, Butt-Welding Fittings.
5. ASME B16.5-2017 - Pipe Flanges and Flanged Fittings.
6. ASME B16.9-2007, Factory-Made Wrought Buttwelding Fittings.
7. American Society for Testing and Materials (ASTM) A193 - Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications.
8. ASME B16.20-2017 - Metallic Gaskets for Pipe Flanges.
9. ASME B16.21-2016 - Nonmetallic Flat Gaskets for Pipe Flanges.
10. ASTM A193 - Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications.
11. ASTM A320 - Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service.
12. ASTM A354 - Standard Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners.
13. ASTM A307 - Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60 000 PSI Tensile Strength.
14. ASTM A194 - Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both.
15. ASME B1.1- Unified Inch Screw Threads, UN and UNR Thread Form.
16. ASME B18.2.1 - Square, Hex, Heavy Hex, and Askew Head Bolts and Hex.
17. ASME B18.2.2 - Nuts for General Applications: Machine Screw Nuts, Hex, Square, Hex Flange, and Coupling Nuts (Inch Series).
18. ASTM A105/A105M-18 - Standard Specification for Carbon Steel Forgings for Piping Applications.