DACC
DRILLING AND COMPLETION COMMITTEE

IRP 29: Temporary Pipework, Securement and Restraint

An Industry Recommended Practice (IRP) for the Canadian Oil and Gas Industry

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29.0 Preface

29.0.1 Purpose

This document defines temporary pipework, provides minimum standards for its selection, implementation and use, and outlines safety measures for its application in the oil and gas industry. Additionally, it provides information about the dynamic forces that can be experienced when there is a piping failure and includes rationale and guidance to manage these risks, such as restraints.

The recommendations within this IRP align with current industry practice and standards for temporary pipework while recognizing jurisdictional differences to provide consistent guidance where regulatory requirements may not be specific or may be contradictory across jurisdictions.

29.0.2 Audience

The audience includes those involved in the planning, set up and use of temporary pipework. This applies to drilling, completions, workovers, well servicing and decommissioning operations.

It is assumed the reader has a basic understanding of wellsite terminology and practices.

29.0.3 Scope and Limitations

The scope of IRP 29 includes land-based operations in western Canada.

The equipment scope is determined by the definitions outlined in 29.2 Definitions. The scope of practice covers the selection, implementation and use of the equipment. This includes the pipework, systems for securement/restraint and anchoring.

IRP 29 covers a broad range of pumping services, from a pump truck injecting methanol to the large multi-well pad hydraulic fracturing operations. The basic principle of protection of the worker, protection of the public and the environment is essential to all operations that utilize temporary pipework.

For this IRP, a temporary pipework system meets the following two conditions:

1. The pipework is used to deliver a pressurized medium:
    a. from a pumping unit into the wellhead or

   b. from the wellhead to an atmospheric or pressurized holding container (e.g., a recovery vessel, tank, flare, holding tanks/C-rings) or temporary surface pipeline.

2. The pipework is used on a temporary basis with the intention of disassembly when the operation is complete.

Due to the inherent risks, similarities and the fact that it is commonly conducted in simultaneous operations, water transfer systems have been included in this IRP. See sec. 29.11 Water Transfer Systems.

29.0.3.1 Out of Scope

This IRP does not cover hard and flexible pipes used for well control.

29.0.4 Revision Process

IRPs are developed by the Drilling and Completions Committee (DACC) with the involvement of both the upstream petroleum industry and relevant regulators. Energy Safety Canada acts as administrator and publisher.

Technical issues brought forward to the DACC, as well as scheduled review dates, can trigger a re-evaluation and review of this IRP in whole or in part. For details on the IRP creation and revisions process, visit the Energy Safety Canada website at www.EnergySafetyCanada.com.

A complete list of revisions can be found in Appendix A.

29.0.5 Sanction

The following organizations have sanctioned this document:

Canadian Association of Oilwell Energy Contractors (CAOEC)

Canadian Association of Petroleum Producers (CAPP)

ENSERVA

Explorers & Producers Association of Canada (EPAC)

29.0.6 Range of Obligations

Throughout this document the terms ‘must’, ‘shall’, ‘should’, ‘may’ and ‘can’ are used as indicated below:

Table 1. Range of Obligation

Term	Usage
Must	A specific or general regulatory and/or legal requirement that must be followed. Statements are bolded for emphasis.
Shall	An accepted industry practice or provision that the reader is obliged to satisfy to comply with this IRP. Statements are bolded for emphasis.
Should	A recommendation or action that is advised.
May	An option or action that is permissible within the limits of the IRP.
Can	Possibility or capability.

29.0.7 Background

IRP 29 establishes best practices for temporary pipework (also called temporary flow piping).

Temporary pipework is mobilized to various well operations and subjected to dynamic conditions, pressure changes and other stresses during storage, transport, and operation. The impact of these changing conditions on the pipework and components used, can be difficult to track without a consistent pipework management system.

There is no single temporary pipework design standard and regulatory requirements vary across western Canadian jurisdictions, which creates the potential for failure. For example, connections may be compatible but may be designed to operate at different working pressures than other components of the system. As well, WorkSafe BC mandates the use of engineered restraint systems to secure temporary flow piping at worksites.

This Industry Recommended Practice provides a uniform, risk-based approach to enhance safety when using a temporary pipework system. The IRP outlines the design, assembly, and potential failure contributors as factors to consider during a site-specific risk assessment for the use of temporary pipework.

29.1 Introduction

IRP 29 provides guidance to industry to identify the risks associated with pipework systems used in temporary applications within the oil and gas sector. The IRP outlines the methodology to identify risk scenarios, components and operations; it also provides a risk register to assist industry in implementing controls (exclusion zones, restraints, procedures) to ensure the protection of workers, the public and the environment. The IRP defines what constitutes temporary pipework, to help employers focus on those specific areas, but also provides guidance for components which may fall outside the definition but still benefit from being managed (i.e., mounted pipework components).

29.1.1 Original Equipment Manufacturer (OEM)

The Original Equipment Manufacturer (OEM) uses standards of engineering and manufacturing such as those provided by the American Petroleum Institute (API) and American Society of Mechanical Engineers (ASME). These standards outline the requirements for the following:

- Design
- Materials
- Welding
- Factory acceptance testing
- Certification
- Documentation
- Servicing/maintenance
- Repairs

References to these standards can be found in Appendix F: References and Resources.

IRP-29 focuses on the selection of temporary pipework, restraints and anchors necessary to meet the requirements of the operation, the operational risks, special considerations for components, in-service inspections, and the required documentation/certifications.

29.2 Definitions

For this IRP and to assist the user, the following definitions will be used throughout IRP 29:

Temporary Pipework

Temporary pipework, also called temporary flow piping, is the system of pipes used at wellsite for pumping into and out of wellbores (wellheads). It includes connections (e.g., hammer unions, flanged connections) and components like joints, valves, tees, and swivels that provide flexibility and adjust the system's orientation and elevation. Temporary pipework is used in services, but not limited to, swabbing, well flowback, cementing, well servicing, and well stimulation. Temporary pipework is the term used throughout this IRP.

Pipework

Pipework is the complete system of pipes, restraints, and anchoring.

Securement

Securement is the anchor point where restraints are attached.

Restraint

Restraint is a safety system designed to control the release of stored energy if temporary pipework fails.

Mounted Pipework

Mounted pipework are pipe systems that are permanently attached to a skid or trailer, such as trailer-mounted or truck mounted piping, and separator skid packages.

Ancillary Piping

Ancillary piping are pipe systems that do not qualify as temporary pipework. Below are common examples:

- Hydraulic hoses for actuating components (e.g., accumulator lines for BOPs, lubricator pack-off/grease injection, ball launcher systems)
- Steam/glycol lines (hard or flexible piping) not pumping into the wellhead

- Hydraulic, electrical, or pneumatic lines connected to wellhead components like emergency shutdown device (ESDs)
- Chemical injection lines
- Fuel lines (e.g., natural gas, propane, diesel) that supply engine driven equipment
- Permanent production piping or flowlines tied to facilities, which are not disassembled after use.

Water Transfer

Water transfer is moving water with pumps using layflat hoses or other means, excluding tank trucks. Water transfer does not include tying to a wellhead, test package, or pressure vessel. Water transfer can occur on lease or off lease. See 29.11 Water Transfer Systems.

29.3 Planning

29.3.1 Objectives

The primary objectives when planning a temporary pipework system are to ensure the following:

- Protection and safety of workers and the public
- Protection of the environment
- Protection of equipment and property
- Mitigation of the risks of a temporary pipework failure through use of controls.

29.3.2 Roles and Responsibilities

Temporary Pipework is used for various services, from large bore high-pressure pipes for hydraulic fracturing to flowback piping, service rig piping connected to the wellhead, pressure trucks and hot oilers.

IRP The Owner and/or Prime Contractor shall verify the operation complies with local jurisdictional regulations.

IRP The Owner and/or Prime Contractor shall provide to any service connecting to a well, the expected pressures, expected wellbore fluid composition, and maximum working pressures.

IRP The Service Company shall ensure that equipment and piping meet the scope of work requirements.

IRP The Service Company shall keep records of temporary pipework meeting the minimum requirements specified in 29.3.3, Pipework Management System.

IRP The Restraint Owner shall ensure the restraint system meets dynamic force requirements and is properly installed, maintained, and repaired.

29.3.3 Pipework Management System

The Pipework Management System, also known as an Iron Management System, helps monitor the condition of the pipework to prevent failures. This system includes managing temporary pipework, such as flexible hoses.

IRP All temporary pipework components shall be managed and tracked using a pipework management system.

IRP At a minimum, the pipework management system should include

- identification and tracking system,
- maintenance schedule tracking,
- certification and recertification records and requirements,
- documented inspections and repairs,
- manufacturer's operational specifications.

29.3.3.1 Storage Requirements

IRP These storage procedures should be followed:

- Clean and lubricate any components requiring lubrication with OEM-approved products.
- Coat threads with a fluid to prevent rust.
- Store in a manner to prevent damage to threads, face or body.
- Flush if used in produced water and/or corrosive pumping operations, to prevent rust.
- Protect elastomers from ultraviolet rays.

29.3.3.2 Transport Requirements

IRP These transportation procedures should be followed:

- Transport in a manner to protect the threads and seals and prevent anything from entering the pipe.
- Transport in a manner that prevents components from impact with each other (which may cause wear and damage).

29.3.4 Evaluating Risk and Choosing Controls

There are many different potential hazards to temporary pipework systems. These hazards need to be controlled based on a risk assessment of their likelihood and potential severity. The complexity of the operation will drive the complexity of the risk assessment.

IRP A risk assessment of potential hazards shall be completed and documented. The IRP 29 Risk Register (see energysafetycanada.com) provides examples of common risks associated with temporary pipework, for reference.

IRP The use of the risk assessment and controls shall not be used to bypass local jurisdictional requirements without the proper regulatory variance application.

Various controls can be used to reduce the risks to workers, the public and environment in the event of a temporary pipework system failure. These controls may include engineering controls, such as restraint systems, and/or administrative controls, like procedures or establishing an exclusion zone. Controls are identified based on a risk assessment.

Key inputs to the risk assessment are as follows:

- Pipework system design: Considerations and risks related to the pipework design, including
  - Review of the IRP 29 Risk Register
  - Pipework management: Maintenance and certifications
  - Component selection: Pipe, connections, other components, mounted components, restraints, anchor points
  - Pressure source (e.g., wellbore, pump truck, gas cylinder)
- Pipework system assembly
  - Inspections
  - Assembly practices
- Pipework system potential equipment failure factors
  - Fluid types
  - Pressures
  - Pipework system parting (dynamic) forces

IRP A risk assessment shall be completed for each of these inputs to determine the appropriate controls for the specific application.

IRP Completed risk assessments shall be communicated to the appropriate parties involved in the work.

IRP A management of change process shall be used to document and manage the risks associated with changing operating conditions. Changes shall be communicated to the appropriate parties involved in the work.

IRP Dynamic force calculations shall be used during the design phase to determine the expected forces and the required strength of restraints when

pipe restraint systems are used. See Appendix B: Restraint Force Equation Theory and Examples, for examples of these calculations.

IRP Consideration should be given to the pressure source's maximum pressure output as it may limit the forces the system could experience.

Note: The equations provided in 29.3.5 Understanding Dynamic Forces Related to Restraint Design and 29.6.2 Restraint Force Equations are not mandatory but are offered as an alternative when no other method is available.

29.3.5 Understanding Dynamic Forces Related to Restraint Design

Understanding dynamic forces caused by pipe breaks or connections parting, is essential when designing and selecting restraint systems for temporary pipework. These forces occur when a pipe system fails, releasing fluid or gas under pressure.

IRP The applicable dynamic forces shall be determined by a competent person to select a restraint system capable of withstanding those forces and preventing accidents.

Temporary piping connected to a well is usually used to either flow fluid from the well or pump fluid into the well. For potential pipe break situations related to restraint system design and selection these two scenarios are described as shown below:

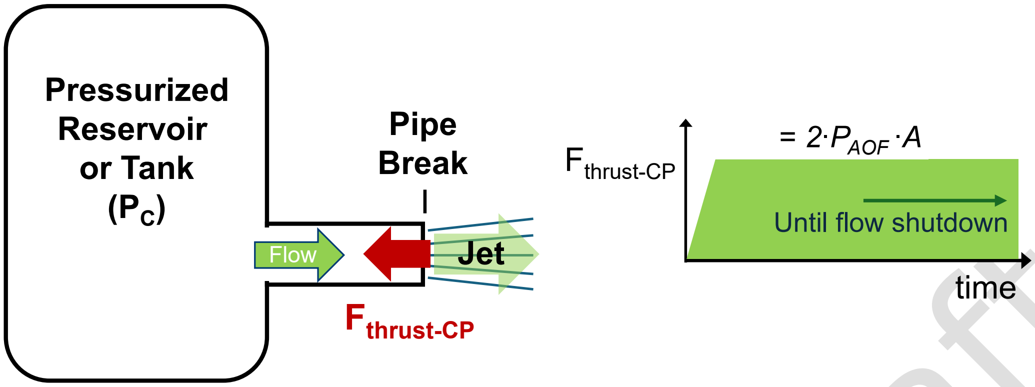
1. Constant Pressure Source Scenario (Wellbore Model) where fluid(s) flows from the well, or
2. Constant Flow Rate Source Scenario (Pump Model) where fluid(s) is pumped into the well.

Note: It is possible for both scenarios to develop during a single pipe break event. The two scenarios in which a full pipe break or separation are assumed to represent worst case conditions in terms of potential restraint loading, are explained in further detail below.

29.3.5.1 Constant Pressure Source Scenario (Wellbore Model)

If temporary piping breaks while flowing fluids from the well (i.e., Wellbore Model), a fluid jet will form almost instantaneously, exiting from the broken pipe, and the pressurized reservoir will continually flow fluid through the broken pipe with a constant pressure until the flow is shut off. The shutoff could take seconds to hours depending on factors like the break location, safety system (e.g., emergency shutdown devices) and personnel response time. The resulting thrust force acts immediately on the restraint system, which must handle the full force of the fluid jet. See Figure 1. Constant Pressure Source Wellbore Model.

Figure 1. Constant Pressure Source Scenario (Wellbore Model)



In this case, the pipe segment near the break experiences a dynamic thrust force from the fluid jet. If the system is operating at full pressure when the break occurs, the thrust force peaks almost instantly and is transferred to the restraint, depending on the movement of the pipe ends. If the broken pipe can move freely, the restraint bears the full force; if anchored, the anchor takes most of the load. Regardless, the thrust force continues until the flow is stopped, so the restraint must be designed to handle the maximum thrust force. In the Wellbore Model, the thrust force can be calculated using the following equation:

Equation 1. Thrust Force in Constant Pressure Source Scenario (Wellbore Model)

$$FthrustCP = Ct(Pc \times A)$$

Where

$F_{thrust\text{-}CP}$ (Thrust Force) is the thrust force applied to the pipe in Newtons (N).

C_t (Thrust Coefficient) is 2.0 for incompressible fluid. For compressible fluids (like gas or steam) the coefficient is typically 1.26.

P_C (Constant Pressure) is the constant pressure of the source feeding the pipe break (for restraint design, this can be assumed equal to the wellhead pressure, P_{AOF}, that can be expected to occur under sustained Absolute Open Flow (AOF) conditions for the well in question, or the maximum tank pressure if the flow originates from a surface vessel), measured in Pascal (Pa).

A (Cross Sectional Area of Pipe) is the cross-sectional area of the temporary pipe bore in square metres (m^2).

> **Note:** The thrust coefficient of 2.0 in the above equation applies to frictionless flow of incompressible fluids. In compressible (like gas or steam) or multiphase flow conditions, a lower thrust coefficient, typically 1.26, may apply.

IRP Lower thrust coefficients should only be used after a competent engineering assessment for the specific installation or operation. It no assessment is available, the thrust coefficient of 2.0 should be applied for all constant pressure source applications, including both incompressible and compressible flow situations.

IRP For the Constant Pressure Source Scenario (Wellbore Model), the pipe pressure should be selected based on the maximum sustained wellhead pressure that could occur during unrestricted flow to surface.

Note: This pressure could be impacted by the charged or induced pressure from fracturing operations resulting in a potential flowing pressure that is higher than would be produced by the native reservoir pressure.

IRP For the Constant Pressure Source Scenario (Wellbore Model), the restraint should be designed to withstand at least the full thrust force generated by the fluid jet from the parted pipe.

Note: The calculated thrust force will act on the unanchored pipe segment at the break, causing it to move and stretch the restraint. The restraint will pick up the load until the force matches the full thrust, which will persist until the flow is shut off.

IRP The owner and/or prime contractor shall provide the highest anticipated wellhead pressure to determine potential restraint loads.

29.3.5.2 Constant Flow Rate Source Scenario (Pump Model)

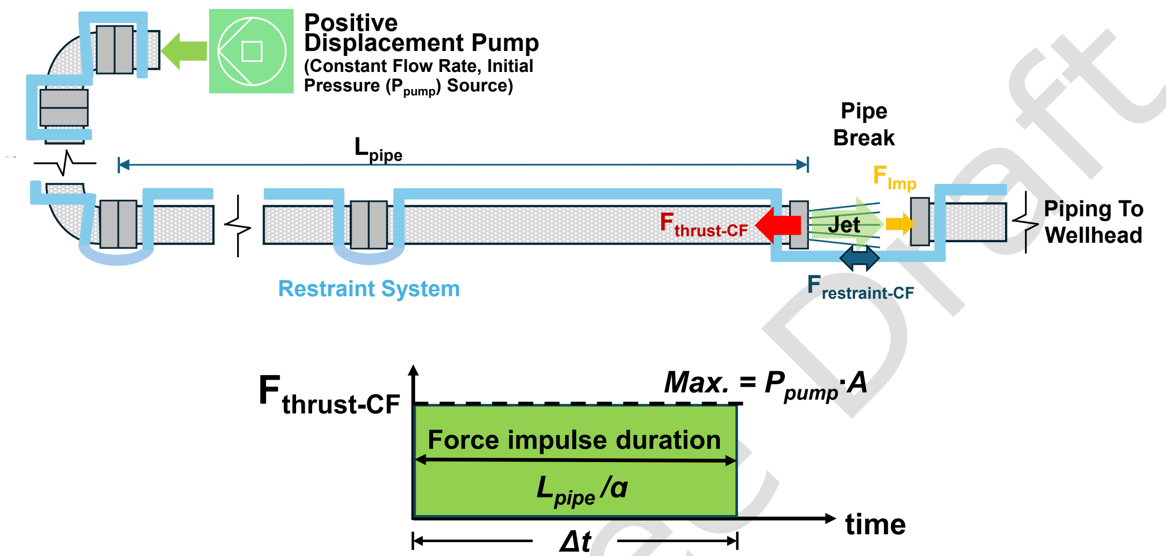
If temporary pipe parts while pumping into a well (i.e., Pump Model), the flow will be at a constant rate initially.

Note: The Pump Model is applicable only for incompressible fluid flows.

In this scenario, it is assumed that the parted pipe segment is connected by the upstream piping system to a positive displacement pump and therefore the pipe pressure at the break will be the pump pressure (Ppump), and the flow will continue until the pump is shut off (See Figure 2: Constant Flow Rate Source Pump Model). After the break, the pipe will depressurize to atmospheric pressure, and a pressure wave will travel through the system at the speed of sound (for the fluid), causing the thrust load to drop quickly. The length of the pressure wave (Lwave) is proportional to the time required for the pipe to fully part during the break, typically one millisecond. Given the short depressurization time, where the load drops to zero as soon as the pressure wave reaches the end of the broken pipe, the forces on the pipe and restraint will change very quickly before entering a steady state condition (i.e., be transient). The restraint will absorb the thrust force until the flow stops. Due to the short transient loading conditions, both the thrust force and the forces acting on the restraint need to be derived from impulse theory. See Figure 2. Constant Flow Rate Source Pump Model.

Note: A similar pressure wave will also travel from the break point through the piping on the other side toward the wellhead.

Figure 2. Constant Flow Rate Source Scenario (Pump Model)



In the Pump Model, the transient thrust force can be calculated using the following equation:

Equation 2. Thrust Force in Constant Flow Rate Source Scenario (Pump Model)

$$\boldsymbol{FthrustCF = Ppump \times A}$$

Where

$F_{thrust\text{-}CF}$ (Thrust Force) is the transient thrust force in Newtons (N)

P_{pump} (Pump Pressure) is pump pressure at the time of the break in Pascal (Pa)

Note: For restraint design, this can be assumed equal to the maximum pump pressure expected to be required to complete the planned well operations, or alternatively for additional conservatism, one could assume the full pressure rating of the piping system.

A (Cross Sectional Area of Pipe) is a cross-sectional area of the temporary pipe in square metres (m^2).

Note: Given the very short time required for pipe depressurization, a constant flow condition may also be assumed for installations employing a centrifugal pump source.

IRP As described further in Section 29.6.1 Restraint System Design, to calculate the maximum force applied to the restraint, the following parameters shall be considered:

- The magnitude of the transient thrust force applied to the pipe with time (i.e., impulse load), depends on the initial pressure and pipe area.
- The length of the pipe that is free to move (L_{pipe}) affects how much the pipe will move.
- The duration of the thrust force impulse is proportional to $L_{pipe.}$
- The mass of the pipe that is free to move is also proportional to $L_{pipe.}$
- The restraint spring factor is a property of the restraint product.

Note: In most cases it is anticipated that temporary piping systems will be pressure tested before commencing the intended operations. Should a pipe break occur during such an installation proof test, the Pump Model scenario would apply in terms of use for the pipe thrust and restraint force calculations.

29.3.5.3 Restraint Design Considerations for Wellbore and Pump Models

Both the Wellbore and Pump models involve rapid loading of the restraint system, which needs to be factored into the design.

IRP The end user should account for the forces exerted on the restraint in both constant pressure and the constant flow rate scenarios. The larger of the two forces should be used in the restraint design and selection.

In hydraulic fracturing, both the wellbore and pump models can occur during a single pipe break event. Initially, the pipe is pressurized and fed by a constant flow rate source, causing the restraint across the break to experience impulse loading (with a peak thrust force of FthrustCF = Ppump x A). After the transient event, if the well is not secured, the well may flow back, leading to a constant pressure scenario with a steady-state thrust force (FthrustCP = $2P_{AOF}$ x A). The forces acting on the restraint may differ greatly in magnitude and duration between these scenarios, and both must be factored into the restraint design.

Long duration flowback, especially if unrestricted, can impose greater demands on the restraint system's capacity and integrity due to sustained loading. This potential impact needs to be considered in the design for hydraulic fracturing and well testing operations.

Table 3 summarizes the thrust forces and restraint loads for both pipe break scenarios, highlighting key differences. See 29.6.1 Restraint System Design and 29.6.2 Restraint Force Equations for further details.

Table 2. Summary of Thrust and Restraint Loading Formulations

Scenario	Thrust Force	Force on Restraint
Constant Pressure Source (Wellbore Model)	$F_{thrust-CP} = 2\,P_{AOF}\,A$	$F_{restraint-CP} = 2\,P_{AOF}\,A$
Constant Flow Source (Pump Model)	$F_{thrust-CF} = P_{pump}\,A$	$F_{restraint-CF} = \frac{P_{pump}\,A\,L_{pipe}}{a}\sqrt{\frac{k_{restaint}}{m_{pipe} + m_{fluid}}}$

Table 4 identifies what field operations would apply the wellbore and pump models.

Table 3. Field Examples of Wellbore and Pump Model Application

Operation	Constant Pressure Source (Wellbore Model)	Constant Flow Source (Pump Model)
Pumping or injecting into a well	X	X
Kill operations	X	X
Hydraulic fracturing	X	X
Cementing operations	X	X
Flow testing operations	X	

29.4 Pipework System

The pipework system includes the connections attached to the piping and premanufactured components such as valves, tees, and swivel joints. The supplier and OEM are responsible to meet the applicable codes and standards for the pipework system.

IRP **The end user shall provide the necessary specifications to the supplier/OEM to ensure that the temporary pipework system will meet the requirements of pressure, temperature, sour service, flow rates, and fluid/material compatibility.**

29.4.1 Piping

The piping for temporary pipework falls into two categories: hard and flexible. Hard piping is constructed of a rigid material such as steel, fiberglass, plastics or other alloys. Flexible piping is constructed of a flexible material such as polyurethane, rubber, braided lines and other malleable materials. The flexible hoses discussed in this section are layered high-pressure hoses.

Note: Low-pressure hoses are not connected directly to the wellhead and are not part of the scope for this IRP (as per 29.2 Definitions). However, considerations for low pressure hoses used for water transfer are discussed in section 29.11 Water Transfer Systems.

Note: Connections and components are used for both hard and flexible piping.

29.4.1.1 Sour Service Requirements

IRP **All pipework used in sour service applications shall meet the requirements of National Association of Corrosion Engineers (NACE/NACE International - now The Association for Materials Protection and Performance (AMPP)) MR-0175 Metals for Sulphide Stress Cracking and Stress Corrosion Cracking Resistance in Sour Oilfield Environments.**

Figure 3. Hydraulic Fracturing Pipework System Before Restraint Application

Figure 4. Temporary Flowback

Figure 5. Restraints Used During Fracture Operations

Figure 6. Large Bore Fracture with Restraints

Figure 7. Discharge Iron from Fracture Pumpers to Manifold Trailer with Restraints

Figure 8. Discharge Iron from Fracture Pumpers to Manifold Trailer with Restraints

Figure 9. Discharge Iron from Fracture Pumpers to Manifold Trailer with Restraints

Figure 10. Discharge Iron from Fracture Pumpers to Manifold Trailer with Restraints

29.4.2 Hard Piping

IRP-29 does not provide information on the manufacturing and assembly of connections to hard piping. The IRP focuses on steel seamless pipe manufactured under the following standards:

- American Society of Testing Materials (ASTM; now ASTM International) A106 Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service
- ASTM A53 Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless
- ASTM A333Standard Specifications for Seamless and Welded Steel Pipe for Low-Temperature Service
- ASTM A334Standard Specification for Seamless and Welded Carbon and Alloy-Steel Tubes for Low-Temperature Service
- American Petroleum Institute (API) Specification 5L Line Pipe

29.4.2.1 Certification Requirements

IRP At a minimum, hard pipe shall be certified by a competent person, as per local jurisdictional regulations for pressure safety equipment.

Certification requirements may include any or all the following for hard pipe:

- Ultrasonic testing (UT) annually (non-destructive)
- Magnetic particle inspection annually
- UT testing periodically for higher loading operations (e.g., high volumes of sand and high velocity pumping/flow where increased risk of erosion is present)
- Visual inspections pre/post job for visible signs of wear (e.g., washing, segments, wing, O-ring, sealing face)
- Checking fabrication codes: Canadian Standards Association (CSA) B51 Boiler, Pressure Vessel, and Pressure Piping Code
- Checking that pressure piping has manufacturing certification to the applicable standard such as API and ASME
- Following OEM specifications

29.4.3 Flexible Piping

Flexible piping can safely be used in high-pressure pumping applications with the appropriate controls in place and can provide operational and safety benefits in some applications. Services include mud and cement hoses, choke and kill lines, and well stimulation hoses. The API specification to which these hoses are manufactured will depend on the service the hose will be used for.

Figure 11. Flexible Fracture Hose

Figure 12. Flexible Fracture Hose

Figure 13. Flexible Fracture Hose

29.4.3.1 Codes and Standards

The following codes and standards are referenced in this section:

- API Specification 7K Drilling and Well Servicing Equipment, Sixth Edition, December 2015
- API Specification 16C Choke and Kill Equipment, Third Edition, March 2021
- API Specification 17J Specification for Unbonded Flexible Pipe, Fourth Edition, May 2014
- API Specification 17K for Bonded Flexible Pipe, Third Edition, August 2017
- API Recommended Practice 17B for Recommended Practice for Flexible Pipe, Fifth Edition, May 2014, Reaffirmed, March 2021

29.4.3.2 Construction and Connections

Flexible piping is designed to fail differently from hard piping. The flexible piping body is constructed in multiple layers to meet the required pressure, temperature, fluid type, and the external environment the flexible pipe will be exposed too. These layers are typically comprised of the following:

- inner rubber liner providing the sealing membrane,
- reinforcement cables or textiles providing the pressure strength,
- outer rubber cover providing protection of the reinforcement from the external environment.

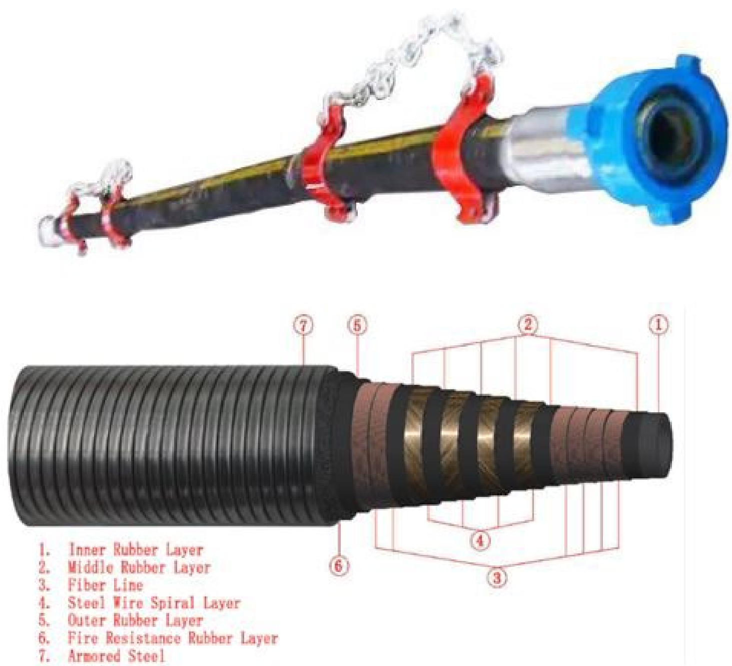
Depending on the service for which the flexible pipe will be used, the construction may include the bonding of the reinforcement layers as defined in API Specification 17K Specification for Bonded Flexible Pipe or unbonded reinforcement layers as defined in API Specification 17J Specification for Unbonded Flexible Pipe. The operator and/or service company may require additional certifications.

Flexible piping connections are available with hammer union, hub/clamp, or flange connections.

IRP High pressure mud and cement hoses meeting API Spec 7K – Drilling and Well Servicing Equipment shall not be used for the pumping of air, gas, well bore hydrocarbons.

IRP Owners and/or Prime Contractors should ensure the type of flexible hose is compatible with the service in which it is used.

Figure 14. Flexible Piping Examples (high pressure)



29.4.3.3 Transport Requirements

IRP **Flexible piping shall not be transported in a manner that exceeds the bend radius specified by the OEM.**

IRP **Flexible piping shall be supported as per OEM recommendations during transport.**

29.4.3.4 Potential Hazards

Consider the following in the hazard assessment:

- Characteristics of the flow stream
- Temperature variance both internal and external.
- Chemical compatibility to meet OEM requirements (e.g., hydrogen sulphide (H_2S), carbon dioxide (CO_2), acids)
- Potential energy in the hose ends during assembly and disassembly from trapped pressure.
- Static buildup and electrical continuity of the hose (See IRP 04: Well Testing and Fluid Handling)
- Radiant heat of surfaces during hot flow or pumping (this could include hoses in the tank farm area during flow back)

- Line of fire hazards that may create contact with the following:
    - Pressurized fluids that may penetrate the skin and inject fluids into the body
    - Steam that may cause burns
    - Chemicals that may pose health effects
    - Potential or unintended movement of hoses (e.g., whipping or flailing of lines or hoses)
    - Ice plugs or hydrates when bleeding off pressure during winter operations
- Release of the following:
    - Flammable fluids that may ignite
    - Hazardous vapors that may be inhaled
- Uncontrolled movement of components (e.g., hydraulic powered pump, coil tubing reel)
- Triggers that can cause pressure to be released such as the following:
    - Exceeding pressure limits
    - Hammering on pressured High Pressure Containing Components
    - Failing to follow proper procedures
    - Using improper or deficient equipment
    - Changing conditions in work processes
    - Failure to communicate changes to original rig in or operational procedures
- Inadvertent release (e.g., due to unknown trapped pressure)
    - Ice plugs, valves/check valves without proper bleed off points
    - Failure to understand the fluid path

29.4.4 Connections

The following are commonly used temporary connections on hard and flexible piping. Not all connections are covered in this section.

- Hammer unions
- Threaded unions
- Flanged connections
- Clamp/hub connections

Other connection types are available but are not commonly used.

IRP Inspections should include, at a minimum, a visual inspection conducted by a competent person of all connections for obvious damage such as the following:

- Abnormal wear
- Visible cracks
- Impact damage
- Erosion and erosion-corrosion
- Other
  - Corrosion, pitting, percentage of wall loss
  - Thread damage or bolt or receptacle

IRP Connections shall be evaluated to ensure there is no mismatch of connections and no failure mechanisms.

IRP If the proper identification (i.e., size, style, and pressure rating of connection) of a connection cannot be confirmed the component shall be removed from service and marked as out of service.

IRP If at any time the condition or integrity of the connection is in doubt, it shall be removed from service and marked as out of service.

29.4.4.1 Hammer Unions

Hammer Unions or "Hammer-seal" unions are the most common union used in oilfield applications due to their quick and easy make up and broad working pressure ranges. Hammer unions consist of a threaded female sub and a male sub with the hammer/wing nut.

An important component is the sealing ring which is energized by the hammer nut and the metal-to-metal sealing faces of the female and male subs.

Figure 15. Hammer Unions High Pressure Containing Components (HPCC) Construction Types

Pressure seal (PS) represents a tapered thread (National pipe tapered or NPT, Line pipe thread or LPT) that relies on compression and contact between the mating threads to create the functional seal. This type of thread has a maximum pressure rating (per API 6A) of 10,000 psi depending on the nominal diameter.

Non-pressure seal thread (NPST) includes an API casing tapered thread profile in the design. However, it differs from PS in that the threads are permanently bonded using an anerobic epoxy. In addition, a traditional hammer union seal is incorporated in the seal pocket which prevents the threads from being exposed to the pressurized fluid. This assembly is suitable for working pressure up to 15,000 psi.

29.4.4.1.1 Hammer Union Identification

Hammer Unions are designated by a size and figure type, along with the rated Cold Working Pressure (CWP). Location of the designations will be on the male/female sub and casted into the wing nut.

Figure 16. Example Hammer Union Identification

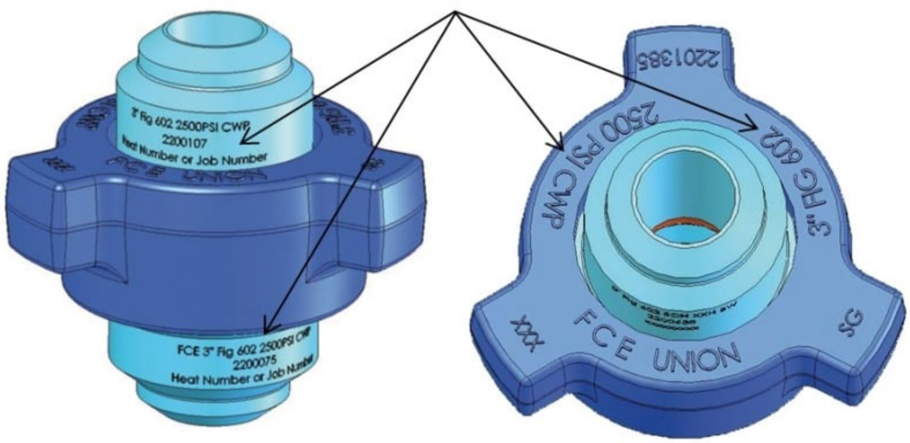


Table 5 identifies types and pressure ratings for commonly used hammer unions.

Table 4. Hammer Union Specifications

Hammer Union Specification Type	Standard Service Pressure Rating Working/Test (psi)	Sour Service Pressure Rating Working/Test (psi)
100	1,000 / 1500	NA
200	2,000 / 3,000	NA
206	2,000 / 3,000	NA
207	2,000 / 3,000	NA
211	2,000 / 3,000	NA
400	2,500 / 3,750	2,500 / 3,750

600	6,000 / 9,000	NA
602	6,000 / 9,000	6,000 / 9,000
1002	10,000 / 15,000	7 500 / 11,250
1003	10,000 / 15,000	7 500 / 11,250
1502	15,000 / 22,500	10,000 / 15,000
2002	20,000 / 30,000	NA
2202	NA	15,000 / 22,500

29.4.4.1.2 Hammer Union Potential Hazards

API Recommended Practice 7HU1, Safe Use of 2-Inch Hammer Unions for Oilfield Applications describes the deadly combination of the two-inch (2”) Figure unions 402, 602, and 1002 being able to make-up to a Figure 1502. The API document recommends a procedural solution to prevent this as a failure will be catastrophic.

Figure 17 illustrates the combinations of two-inch (2”) look-a-like hammer unions that can lead to failure. Figure 18 shows a tool that can be used to ensure there are no mismatched unions for 1502 combinations.

IRP Hammer union connections shall be figure matched.

Figure 17. Mismatched Unions

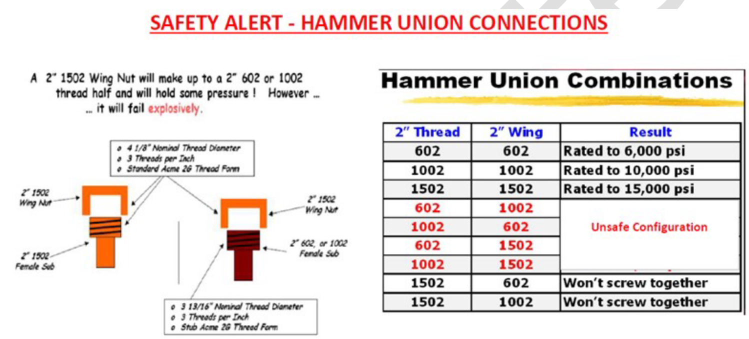


Figure 18. 1502 Go-No-Go Tool

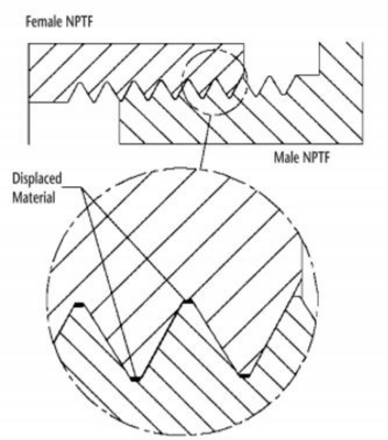
29.4.4.2 Threaded Unions

Threaded unions are two joints secured together with threaded male and female segments. The contact between the threads provides the sealing face. Common threads include National Pipe Tapered, National Pipe Taper Fuel (NPTF), buttress, 8-round, short-threading coupling, and long-threading coupling.

IRP Integral fitting shall only be used where pressure exceeds 3,000 kPa.

IRP NPT fittings must be suitably rated for the Maximum Allowable Working Pressure of the system. See ASME B31.3 Process Piping for different schedules of NPT fitting and the corresponding Maximum Allowable Working Pressure.

Figure 19. Threaded Unions



29.4.5 Flanged Connections

Flanged connections are an assembly of flanges, gaskets and bolting brought together to form a pressure containing connection. The governing standards for flanged connections typically seen on temporary piping are API Specification 6A, Specifications for Wellhead and Tree Equipment and ASME B16.5, Pipe Flanges and Flanged Fittings.

29.4.5.1 API Specification 6A Flanged Connections

API 6A defines the pressure ratings for flange material, gaskets, and bolts/nuts. API Specification 6A governs the design requirements for 6B and 6BX flange types as shown below. All API 6A flanges use a ring-type gasket to achieve a metal-to-metal seal between the mating flanges. This seal is accomplished by inducing ring gasket compression to the ring groove through torquing of the bolts.

29.4.5.2 Flange Identification

IRP All API 6A Flanges shall be marked, at a minimum, with the following information:

- Nominal bore size
- End and outlet connector size
- Rated working pressure
- Ring groove type and number

Table 5. Adapted from API 6A Rated Working Pressures and Size Ranges of Flanges

Rated Working Pressure		Flange Size Range			
		Type 6B		Type 6BX	
MPa	psi	mm	in	mm	in
13.8	2000	52 - 540	2 1/16 – 21 1/4	679 – 762	26 ¾ - 30
20.7	3000	52 - 527	2 1/16 – 20 ¾	679 – 762	26 ¾ - 30
34.5	5000	52 - 279	2 1/16 - 11	346 – 540	13 5/8 – 21 ¼
69.0	10,000			46 – 540	1 13/16 – 21 ¼
103.5	15,000			46 – 476	1 13/16 – 18 ¾
138.0	20,000			46 - 346	1 13/16 – 13 5/8

Equipment needs to be designed to operate in one or more of the specified temperature classes with minimum and maximum temperatures as shown in Table 7, or to minimum and maximum temperature ratings as agreed between the purchaser and manufacturer.

Table 6. Adapted from API 6A Table 2 Temperature Ratings

Temperature Class	Temperature Range			
	Minimum (lowest ambient temperature the equipment can be subjected to)		Maximum (highest temperature of the fluid that can directly contact the equipment)	
	°C	°F	°C	°F
K	-60	-75	82	180
L	-46	-50	82	180
N	-46	-50	60	140
P	-29	-20	82	180
S	-18	0	60	140
T	-18	0	82	180
U	-18	0	121	250
V	2	35	121	250

API 6A states that equipment used at temperatures more than 121°C (250°F) may need to have its rated working pressure (RWP) derated to account for a loss in material strength at these temperatures. An engineering analysis can be completed to determine the allowable pressure of the equipment at these temperatures or, alternatively, the RWP of the API 6B flanged connections can be derated as per Table 8.

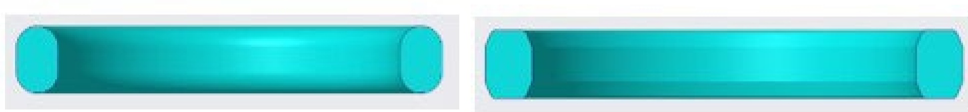
Table 7. Adapted from API 6A Table G.2 Optional Pressure-Temperature Ratings for 6B Flanges

Pressure Rating for Classes K to U		Derated Pressure			
		Class X		Class Y	
MPa	psi	MPa	psi	MPa	psi
13.8	2000	13.1	1905	9.9	1430
20.7	3000	19.7	2860	14.8	2145
34.5	5000	32.8	4765	24.7	3575
138.0	20,000			46 - 346	1 13/16 – 13 5/8

29.4.5.3 Ring Gasket Types

IRP A new ring gasket shall be used every time a flange is made up. For API 6A flanges, an API 6A monogrammed ring gasket shall be used.

Figure 20. R Gaskets



This ring groove gasket is used in flanges up to 5000 psi. It fits into 6B flanges and is available as either an octagonal or oval cross section. This ring gasket has the same nominal pitch diameter as the groove it sits in. When placed into the groove it should contact, or nearly contact, the groove on both its Outside Diameter (OD) and Inside Diameter (ID). When properly assembled there will be an S Ref between the two flange faces of approximately 3/16” (see Figure 21).

Figure 21. API 6A Type 6B Flange with ‘R’ Gasket and S Ref = 3/16”

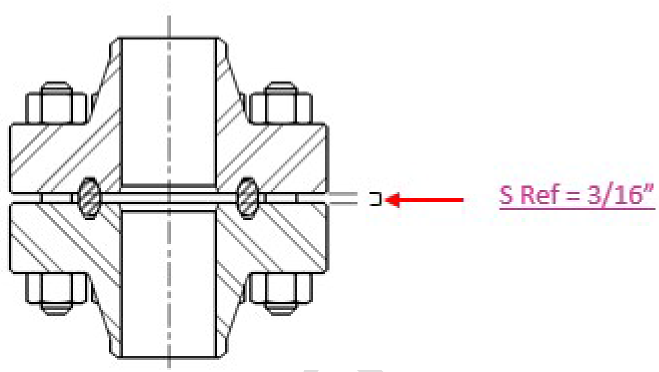


Figure 22. RX Gaskets

RX gaskets are pressure-energizing versions of an R gasket. This ring groove gasket is interchangeable with R gasket grooves and fits into 6B flanges. This gasket has a slightly larger pitch diameter than the groove it fits into. When placed into its groove it should clearly contact the OD and fit loosely with the ID. This fit compresses the gasket not only vertically, but also radially storing more energy and creating a higher contact load on the OD of the seal. The S Ref between flanges is approximately a half an inch (½”) (see Figure 23).

Figure 23. API 6A Type 6B Flanges with 'RX' Gasket and S Ref = ½"

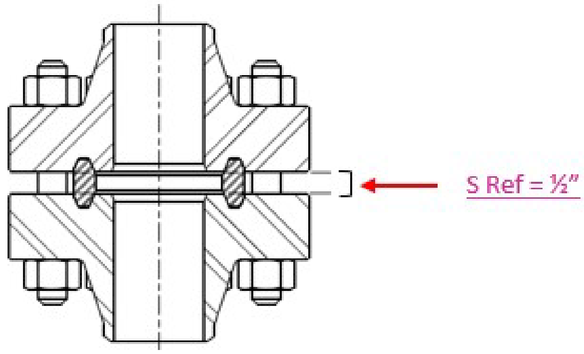
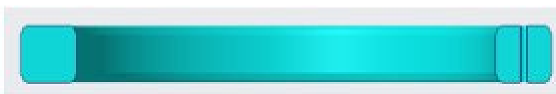
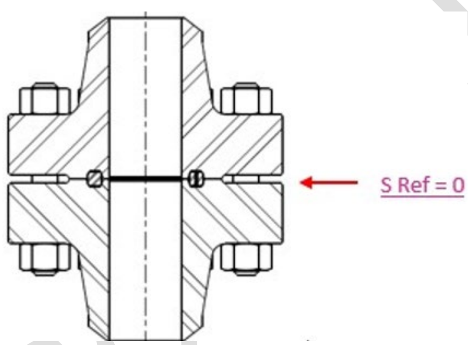


Figure 24. BX Gaskets



The BX ring groove gasket is used in flanges up to 20,000 psi. These fit into 6BX flanges and the design requires that at least one of the joining flanges has a raised face. They can only fit into BX style ring grooves and face to face contact is required between the flange faces when properly made up (S Ref=0, see Figure 25). The BX gasket contacts both the ID and OD of its mating groove but is designed to primarily seal on the OD of the groove. They also have a pressure balancing hole through the x-section.

Figure 25. API 6A Type 6BX Flange with 'BX' Gasket and S Ref = 0 (flanges face to face)



29.4.5.4 Bolting

The final component in a flanged connection is the bolting, to provide the necessary compression for proper sealing of the ring gasket. ASTM provides the bolting standards for 6B and 6BX flanges. The proper torque provides two effects:

1. Coning
2. Intimate Contact

Coning is when two metal surfaces of different hardness come into contact, causing the softer material to deform to match the exact shape and finish of the harder material. This is completed by the bolt/nut proper torque. Intimate contact is a condition when material specifications match and are forced together that leaves no space or gap and is also completed with the proper torque valves on the bolt/nut.

29.4.5.5 Recommended Make-up Torque

The torque valves given in API 6A Annex H corresponded to the desired tension required in the bolting to achieve proper flange sealing and functionality and induce a stress in the bolt of 50% of the bolt yield. To use these tables, it is necessary to know the nominal stud size and the yield strength of the bolt material. The nominal size of the stud is the measured outside diameter of the stud. The bolt material grade will be stamped on the end of the studs to identify its material.

The following are the common stud grades used in Canada:

- B: High temperature/High Pressure
- L: Low Temperature, Outdoor Service
- M: Sour service

The yield strength of these common stud grades is as follows:

- ASTM A193/A193M grade B7M: yield strength = 550 MPa (80,000 psi)
- ASTM A320/A320M grade L7M: yield strength = 550 MPa (80,000 psi)
- ASTM A193/A193M Grade B7: yield strength = 720 MPa (105,000 psi)
- ASTM A320/A320M grade L7: yield strength = 720 MPa (105,000 psi)

IRP The following flanges should not be made up beyond 275 MPa (40 000 psi) bolt stress due to potentially high flange stresses:

- 346 mm (13 5/8 in): 13.8 MPa (2 000 psi)
- 425 mm (16 3/4 in): 13.8 MPa (2 000 psi)
- 540 mm (21 1/4 in): 13.8 MPa (2 000 psi)
- 346 mm (13 5/8 in): 20.7 MPa (3 000 psi)
- 425 mm (16 3/4 in): 20.7 MPa (3 000 psi)
- 527 mm (20 3/4 in): 20.7 MPa (3 000 psi)

Table 9 shows the recommended torques when bolting flanges. Two coefficients of friction are shown. A coefficient of friction of 0.13 approximates the friction with threads and nut bearing surfaces being bare metal and well lubricated. A coefficient of friction of 0.07 approximates threads and nut face coated with fluoropolymer material. Proper torque and S Ref based on ring gasket type, (see Figures 21, 23 and 25) are key to ensuring the flanges are made up properly.

Table 8. Adapted from API 6A Table H.1 Recommended Torques for Flange Bolting

Stud Diameter	Threads per Inch	Studs Sy = 550 MPa Bolt Stress = 275 MPa			Studs Sy = 720 MPa Bolt Stress = 360 MPa			Studs Sy = 655 MPa Bolt Stress = 327.5 MPa		
		Tension (F)	Torque (f = 0.07)	Torque (f = 0.13)	Tension (F)	Torque (f = 0.07)	Torque (f = 0.13)	Tension (F)	Torque (f = 0.07)	Torque (f = 0.13)
Inches	1/in.	kN	N-m	N-m	kN	N-m	N-m	kN	N-m	N-m
0.500	13	25	36	61	33	48	80			
0.625	11	40	70	118	52	92	155			
0.750	10	59	122	206	78	160	270			
0.875	9	82	193	328	107	253	429			
1.000	8	107	288	488	141	376	639			
1.125	8	140	413	706	184	540	925			
1.250	8	177	569	981	232	745	1285			
1.375	8	219	761	1320	286	996	1727			
1.500	8	265	991	1727	346	1297	2261			
1.625	8	315	1263	2211	412	1653	2894			
1.750	8	369	1581	2777	484	2069	3636			
1.875	8	428	1947	3433	561	2549	4493			
2.000	8	492	2366	4183	644	3097	5476			
2.250	8	631	3375	5997	826	4418	7851			
2.500	8	788	4635	8271	1032	6068	10,828			
2.625	8							1040	6394	11,429
2.750	8							1146	7354	13,168
3.000	8							1375	9555	17,156
3.250	8							1624	12,154	21,878
3.750	8							2185	18,685	33,766
3.875	8							2338	20,620	37,293
4.000	8							2496	22,683	41,057

29.4.5.6 Nuts

The common grades of nuts used in Canada are ASTM 2HM, 2H, B7M, and L7M.

Note: The yield strength of the nuts does not impact the made-up torque.

IRP Lubrication shall not contain lead, tin, antimony, or bismuth when used for applications above 260°C (500°F).

IRP The connection should be pressure tested to ensure it is valid and leak free.

29.4.5.7 Loading Limitations

The capabilities of API flanges under combination of loading are published in the following API Technical Reports:

- API TR 6AF, Technical Report on Capabilities of API Flanges Under Combinations of Load
- API TR 6AF1, Technical Report on Temperature Derating on API Flanges under Combination of Loading
- API TR 6AF2, Technical Report on Capabilities of API Flanges Under Combinations of Loading - Phase II

IRP API TR 6AF2 should be used as the resource for flange loading limitations.

29.4.5.8 Flange Failure

Flange failure is not always the fault of the ring gasket. The condition of the two flanges and bolting can lead to a leaking flange. A small leak can quickly grow as the high-pressure fluid flowing against the steel can pressure cut the gasket, ring groove and/or flange.

Figure 26. Example Flange Failure

29.4.5.9 Restraint Recommendation

For API 6A flanged connections, the bolting is the restraint system since it prevents a complete separation or catastrophic failure of the connection, so no further restraint is necessary unless required by local jurisdictional regulations.

Note: Based on rigorous design and quality requirements, and the engineering work done for the API Technical Reports (See 29.4.5.7 Loading Limitations), API 6B and 6BX flanges will leak at the ring gasket before there is a catastrophic failure of the bolting and therefore no further restraint is necessary. Non-API flanges must be evaluated to understand their failure modes and failure potential (e.g., destructive test, Finite Element Analysis.).

IRP Flanged pipework is a combination of flanges connected by hard piping. If the proper tracking and identification of the flange is not verifiable then the component shall be removed from service.

29.4.5.10 Recommended Assembly

IRP API flanges shall be assembled as per the manufacturer's specification for the configuration of the flange, sealing element, and pressure and temperature rating to ensure proper makeup of the flange.

IRP API 6A Flanges should be assembled as per API TR6RT Guidelines for Design and Manufacture of Surface Wellhead Running, Retrieving and Testing Tools, Clean-out Tools and Wear Bushings, First Edition.

29.4.5.11 ASME Flanges

ASME Flanges designed for piping applications come in many configurations and materials and fall under several codes and standards. For this reason, we cannot concisely define their requirements in this IRP, however some recommendations for ASME flanges are provided.

Within the ASME standards there are multiple carbon steels, low-alloy steels, high-alloy steels, and nonferrous metals that can be used to make flanges.

IRP Pressure–temperature ratings are maximum allowable working gauge pressures and must be referenced within the tables of the appropriate ASME flange standards. The ASME flange class and construction material are used to identify the operating pressure and temperature.

29.4.5.12 ASME Flange Identification

IRP All ASME/ANSI flanges should be marked with the following:

- The manufacturer's name or trademark

- Material of construction designation
- Flange Pressure Rating Designation (Class)
- Conformance (e.g., ASME B16 Standardization of Valves, Flanges, Fittings, and Gaskets, ASME B16.5 Pipe Flanges and Flanged Fittings: NPS ½ through NPS 24, Metric/Inch Standard, B16.47 Large Diameter Steel Flanges: NPS 26 through NPS 60, Metric/Inch Standard, ANSI/MSS SP-44 Steel Pipeline Flanges)
- Nominal Pipe Size (NPS) or Diameter Nominal (DN)

29.4.5.13 ASME Flange Type and Use

ASME flange types are differentiated by size and class in the various ASME standards. The combination of the flange class and size define the physical geometry of the flange. The common ASME flange types are covered in the following standards:

- ASME B16.5-2020: Pipe Flanges and Flanged Fittings NPS ½ through NPS 24 Metric/Inch Standard
  - Flange sized NPS ¼ through 24
  - Classes 150, 300, 400, 600, 900, 1500 and 2500
- ASME B16.47-2020: Large Diameter Steel Flanges NPS through NPS 60 Metric/Inch Standard
  - Flange sized NPS 26 through 60
  - Classes 75, 150, 300, 400, 600 and 900
- ANSI/MMS-SP-44-2019: Steel Pipeline Flanges
  - Flange sized NPS 12 through 60 Classes 150, 300, 400, 600, 900

The class refers to the ASME B16.5 designation for pressure/temperature ratings (e.g., Class 150, 300, 400, 600, 900, 1500, 2500). The higher the class number, the heavier the flange is.

ASME flange sizes are based on the NPS which is related to the reference nominal diameter. International standards base flange size on DN. The following table shows how Nominal Pipe Size corresponds with DN.

Table 9. Relationship Between NPS and DN (Adapted from ASME)

NPS	DN
½	15
¾	20
1	25
1 ¼	32
1 ½	40
2	50
2 ½	65
3	80
4	100

Note: For NPS ≥ 4, the related DN = 25 multiplied by the NPS number.

29.4.5.14 ASME Flange Assembly

IRP ASME flanges shall be assembled as per the manufacturer's specification for the configuration of the flange, sealing element, and pressure and temperature rating to ensure proper makeup of the flange.

29.4.6 Clamp/Hub Connections

Clamp/hub connections are an assembly of a hub, seal ring, clamp, and bolting.

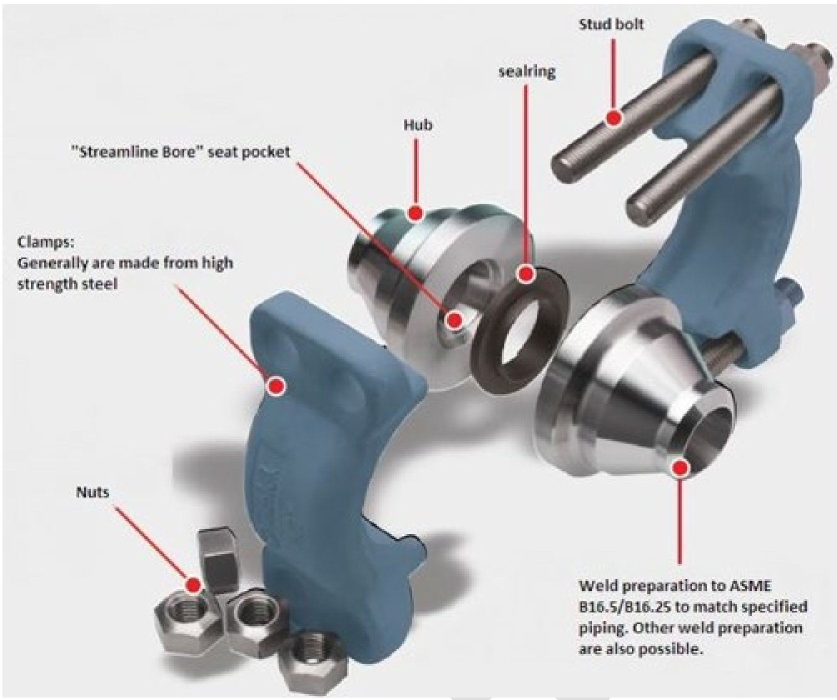
Hub and clamp style connectors are an alternative end connection to an ASME B16.5 or API 6A or 16A flange as they have pressure ratings from 13.8 MPa to 138.0 MPa (2,000 psi up to 20,000psi), provide less bolting and do not have bolt-hole alignment issues. With the four-bolt design you can rotate the clamp to allow for clamping in tight locations and it is lighter and compact.

This type of connector includes three basic components:

1. Hub
2. Sealing ring (could be elastomeric/standard API ring gasket/proprietary mechanically energized seal)
3. Clamp ring with bolting and potentially spherical washers or nuts

The hub and clamp connectors provide a metal-to-metal (some of these are metal to metal seals with an elastomeric back up) seal between the seal ring and the two hub faces machined seat pocket. The seal ring design is also energized under pressure. This style of seal allows for lower bolting torque when compared to a ring style flange which requires the bolt torquing to energize the seal.

Figure 27. Hub/Clamp Connector Four Bolt Design



Hub clamps may also use a standard ring gasket that is energized by the force of the hub clamps. This style is non directional, whereas other versions are.

29.4.6.1 API Specifications 6A and 16A

API 16A provides the design requirements for the clamps being used with the 16B and 16BX hubs. Clamps are given a clamp number based on the hub size and pressure ratings as referenced in API 16 Pressure Ratings and Size Ranges of Type 16B and 16BX Hubs.

29.4.6.2 Hub/Clamp Potential Hazards

IRP Clamps shall be inspected to ensure that they were manufactured under API 6A or 16A. Prior to these API standards being adopted, non-API clamps may not be interchangeable with hubs, seal rings or other clamps that have been manufactured under these API standards.

IRP The correct clamp shall be used with the appropriate hub for the application being proposed. Incorrect selection of ID and pressure rating of the hub may cause failure while incorrect selection of the clamp may

cause complete connection failure if its mechanical connection to the hub fails due to being under or oversized.

Hub clamp connections have several unique concerns that need to be considered:

1. Clamp sections are mated pairs; do not swap individual clamps.
2. The orientation of clamp sections may be important; consult manufacturer specifications for orientation requirements.
3. The integrity of the seal is dependent on the torque value applied to the clamps.

IRP Making up of the clamps should be completed as per the manufacturer's specifications for bolt/nut, pattern, incremental torque makeup, final torque values and the intervals required to re-check the torque values.

IRP Hub and clamp styles of connections are not considered self-restraining and shall be evaluated for restraint.

Some manufacturers will designate a required flow path. Ensure that connections are installed in the proper flow path to reduce the potential for connection failure caused by erosive fluids flowing in the incorrect direction.

29.4.6.3 Special Considerations

IRP Galling (i.e., adhesive wear) of high load surfaces where the clamp engages onto the hub should be inspected after each use. If galling or scoring is found, the hub should be removed from service until it has been repaired as per the manufacturer's recommendations.

IRP Hub mating surfaces should be inspected for corrosion or damage that may impede the hub faces from mating fully. Remove the hub from service and follow manufacturer's specifications for repair.

IRP The condition and orientation of all elastomeric seals in the hub should be inspected. Abnormal wear may indicate incorrect installation/orientation of the seal. Follow the manufacturer's specifications to replace the seal.

29.4.7 Other Piping Components

Other piping components such as joints, valves, burst disks, chokes, laterals, Wyes, elbows and crosses, are used to provide adequate flexibility, orientation and functionality within the pipework system. Understanding that other components in the pipework system can alter flow dynamics is crucial, as they may experience substantial forces and be more prone to wear. For instance, figures 2 and 29 show wear observed on a swivel.

IRP Other piping components should be inspected and maintained to ensure they remain intact and can withstand the forces they are subjected to.

IRP If at any time there is any doubt about the condition or integrity of the component it shall be removed from service and marked as out of service.

Figure 28. Washed Out Swivel

Figure 29. Washed Out Swivel

29.4.8 Mounted Pipework and Manifold Components

Mounted pipework and manifold components include pipework that is permanently mounted to a piece of equipment and is pressurized to flow in or flow out (e.g., trailer, truck, skid) but is not typically removed when mobilizing between job sites. This mounted pipework, utilizes the same components as identified in this IRP. Examples of mounted pipework includes, but is not limited to, the following:

- Manifold system (e.g. choke manifold and pump manifold)
- Reel iron assembly and rotating joint within a coiled tubing unit
- Any piping contained within a trailer or attached to a skid
- Discharge iron assembly on pumping units

The mounts supporting the mounted pipework may only be designed to hold the piping in place during transport but may not be designed to handle the forces during a piping failure.

IRP The equipment owner and/or manufacturer should assess the risks associated with mounted pipework and mitigate the risks to ensure worker safety. This may require installing restraints to the mounted equipment.

Figure 30. Example of Mounted Pipework

There may be situations where the temporary piping system and the mounted pipework are the same design and hence have the same likelihood of failure. A restraint system may be considered as a control measure, however, in some situations, applying a restraint system to the mounted pipework may not be reasonably practicable or could introduce more risk to the workers or the operation. For example, the reel on a coiled tubing unit utilizes hammer union piping inside the reel (i.e., the temporary piping system connecting to the reel). The equipment owner, in consideration of worker safety or operational limitations, may deem it unnecessary to apply a restraint system inside a coiled tubing reel unit. Instead, they may elect to apply adequate anchoring of the temporary piping system to the reel unit, determine the hammer union piping is already self-containing inside the reel and implement an exclusion zone around the reel unit as sufficient mitigation measures to ensure worker safety.

It is the responsibility of the equipment owner and the manufacturer to implement the appropriate measures to ensure worker safety without adding additional risk. See Appendix C: Case Study.

Figure 31. Hammer Union Connections Inside a Coiled Tubing Reel Unit

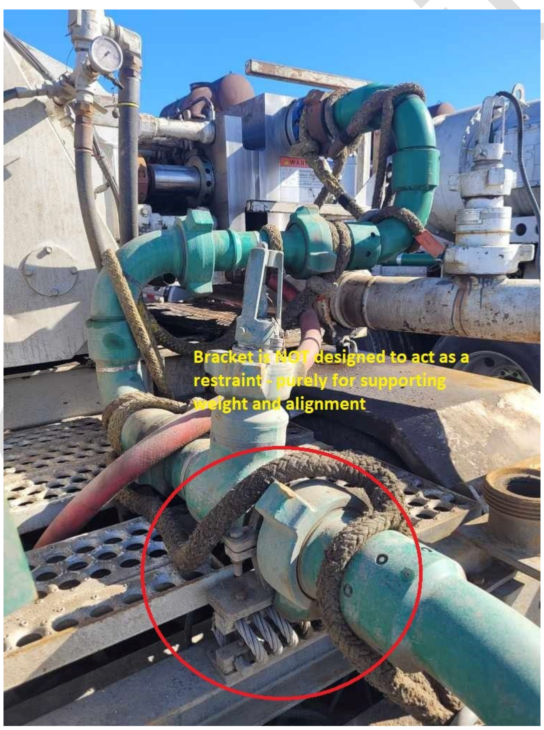
In another example, a pumping unit owner may deem that the mounts supporting the mounted hammer union pipework on a pump unit are not designed to withstand the forces during a failure event and may elect to modify the existing mounts to be engineered to withstand the expected loads.

The following figures show mounted pipework with restraints.

Figure 32. High Pressure Piping on Twin Pumper with Restraints

Figure 33. Fracture Pump Bridle with Restraints

Figure 34. Fracture Pump Bracket



29.5 Pipework System Assembly

This section identifies the recommended practices to assemble the pipework system. Specific details about the selection, use and handling of the piping, components and connections can be found in 29.4.1 Piping, 29.4.4 Connections, and 29.4.7 Other Piping Components.

29.5.1 Pre-Rig In

Manufacturers set recommended flow rates for components based on velocity, to reduce the wear, increase the safety and to improve longevity of the component.

IRP Unless specified by the manufacturer, the maximum fluid velocity for components should not exceed the manufacturer's recommendation (typically 38-42 feet/second).

Note: Often there are components from multiple manufacturers used in the pipework system. They may not all have the same recommended flow rate.

IRP Each component shall be marked with a unique identifier to enable tracking of the component through its service and maintenance cycles.

See Appendix D: Checklists, for a sample Pre-Rig In Inspection Checklist.

29.5.2 Installation and Make Up

IRP The temporary pipework system must be grounded and bonded. See IRP 04 Well Testing and Fluid Handling.

IRP All components shall have clean (i.e., free of ice, mud, dirt, debris) and lubricated connection points.

IRP Components shall be assembled as per the Owner and/or Prime Contractor's site plan (if available) or, at minimum, as per the manufacturer's specifications/recommendations.

IRP All components shall be subject to an inspection during rig in (see 29.5.3.1 Pre-Rig In and Rig Out Inspections and 29.5.3.2 Pre-Use Inspection).

IRP All components should be subject to a similar inspection during rig out (see 29.5.3.1 Pre-Rig In and Rig Out Inspections and 29.5.3.2 Pre-Use Inspection).

Additional periodic inspections may be conducted depending on operating conditions (e.g., operating area, product line, job size, fluid rates, duration), operator procedures or OEM specifications. See 29.5.3.3 Periodic Inspections for more information.

IRP For pumping operations down the wellbore, the piping system shall have flexibility to allow for movement during operations.

Using swivels is one way to facilitate this movement. See 29.5.2.1 Considerations for Swivels in Pumping Operations for more information.

IRP Swivels shall not be used for flowback operations due to their limited lifespan in erosive environments. See IRP 04: Well Testing and Fluid Handling.

29.5.2.1 Considerations for Swivels in Pumping Operations

Swivels provide the temporary pipe with rotational degrees of motion that reduce the impact of external forces on the pipework system and help dampen the vibration. Using one three-way swivel or two two-way swivels provides three points of rotation to accommodate the free movement of the lines in all planes. Using multiple three-way swivels may provide a means to avoid lockup (provide three points of rotation: up and down, left and right, and horizontal).

IRP Swivels should be placed at an angle of 45 degrees or more but should not exceed 100 degrees.

Any angle outside these parameters may not work as designed and allow too much freedom of movement. This also helps to avoid open swivels (which would no longer be able to rotate properly).

29.5.2.2 Considerations for Flanged Connections

Flange alignment is important for achieving the desired temperature and pressure ratings.

IRP Flanges shall be aligned in a manner that avoids applying additional forces on the pipework system.

IRP When assembling ring gasket connections, the ring grooves shall be thoroughly inspected to verify they are clean, undamaged and free from corrosion.

IRP Ring gaskets shall be new and undamaged when assembling.

29.5.2.3 Considerations for Hub/Clamp Connections

IRP The following should be completed to ensure hub/clamp components are clean and in good operating condition:

- Ensure seals are not cracked or worn (replace if necessary).
- Lubricate bolts with an approved lubricant (as defined by the manufacturer).
- Insert the seal ring into one of the bores and ensure it is clean and lubricated with an approved lubricant (as defined by the manufacturer).

When using hub/clamp connections these steps are typically followed:

- Assemble the components and lubricate the internal and external surfaces of the flange as well as the outside surfaces of the seal ring:
  - Pull the flange faces of the pipe sections together as close as possible
  - Position the clamps

  Note: Start the bolts into the bottom clamp, ensuring the bolts are not cross threaded by turning each at least two rotations by hand.

- Ensure contact surfaces are mated correctly (flush and seated) before installing clamps to secure.
- Torque the bolts following the manufacturer's recommended procedures and specifications.
- Verify the assembly is as per the manufacturer's specifications.

29.5.2.4 Considerations for Flexible Hoses

IRP Only end connections that are suitably rated for the intended installation and recommended by the OEM shall be installed.

IRP The bend radius specified by the OEM shall not be exceeded and may require a supporting bracket and sling.

IRP End connections shall be completely clean (i.e., free of ice, mud, dirt, debris) and free from mechanical damage (e.g., burrs).

IRP Seals shall be fitted as per OEM specifications.

IRP Flexible hoses should be protected from potential abrasion, cutting or impact damage.

IRP OEM specifications shall be followed for

- handling (including removing packaging), transportation, storage,
- rig in and rig out,
- care and installation including support, securement, twisting limitations, minimum bend radius, temperature and fluid compatibility,
- maintenance,
- inspection,
- testing.

IRP Options for an engineered system to secure flexible hoses should be evaluated.

29.5.3 Inspections

Inspections are an integral part of safe and effective use of temporary pipework. Visual inspection can identify damage or potential for damage. Types of inspections include the following:

- Inspections as part of the Pipework Management System (Section 29.3.3)
- Pre-rig in/rig out inspections
- Pre-use inspection after assembly (rig in)
- Periodic inspections after assembly.

IRP Inspections shall be completed by a competent person.

IRP If at any time there is doubt about the condition or integrity of the hard or flexible pipe it shall be removed from service and marked as out of service.

IRP Inspections should include, at a minimum, a visual inspection of all hard or flexible piping for damage such as the following:

- Abnormal wear
- Visible cracks
- Impact damage
- Erosion
- Flexible hose connections including the crimp/compression make up between the flexible hose and the end connection

29.5.3.1 Pre-Rig In and Rig Out Inspections

There are multiple types of inspections for hard and flexible piping. They are as follows:

- Visual inspection,
- ultrasonic thickness test,

- borescope inspection,
- Magnetic particle (if required),
- pressure tested to confirm the component and/or system is in suitable condition.

IRP Components that fail the initial visual inspection shall be removed from service until they pass reassessment for service.

IRP Before use, new HPPC documentation shall be reviewed, a visual inspection conducted and identification bands installed.

29.5.3.1.1 Hard Piping

IRP A rig-in or rig-out visual inspection should include the following for hard piping:

- Ensure the union is in good condition and free of defects.
- Ensure all threads are in good condition and clean (use a wire brush or cleaning fluid and scrub brush).
- Lubricate the threads on both thread and wing halves.
- Ensure the insert is present, properly installed and not warped or cracked.
- Ensure all three segments are present, and the snap ring is in position.
- Confirm unions are not mismatched. See 29.6.9 Potential Hazards for more information on mismatched unions.

29.5.3.1.2 Flexible Piping

IRP A rig-in or rig-out visual inspection should be conducted in accordance with API 574 Inspection Practices for Piping System Component and include the following for flexible piping:

- Confirm certification of intended service.
- Inspect the hose along its full length, including the end fittings, paying particular attention to areas of concern (e.g., hoses near equipment, areas of previous hose body repair).
- Check for cuts, abrasions or any other apparent damage.
- Check outer cover for signs of looseness, kinks, bulges, soft spots, signs of abrasion, cuts or gouges.

IRP Cuts or gouges in flexible hoses shall be addressed immediately.

Cuts or abrasions of the hose may be repairable.

IRP If the reinforcement is exposed, the hose should be replaced.

IRP Repairs, service and maintenance performed on the flexible piping shall be performed by a competent repair person (See IRP 07: Competencies for Critical Roles in Drilling and Completions).

29.5.3.2 Pre-Use Inspection

IRP A pre-use inspection should be done to ensure all segments are secured in place and the insert condition and placement is correct.

IRP A pre-use inspection for installed flexible hoses should include checking:

- the outer cover looking for signs of looseness, kinks, bulges, soft spots, signs of abrasion, cuts or gouges,
- the hose body behind the hose end fitting for signs of overbending,
- areas of the hose that are near other steel or equipment edges,
- end couplings for signs of leakage, corrosion, erosion, or cracking of the steel end,
- for an inspection tag (e.g., steel band) and/or record of inspection (based on stamped serial numbers).

29.5.3.3 Periodic Inspections

Follow OEM specifications for periodic inspections and testing of hard or flexible piping. This should be done in accordance with API Recommended Practice 574 Inspection Practices for Piping System Component, including verification of design considerations and service compatibility, diameter, length, fitting, and pressure ratings.

29.5.3.4 Post-Installation Inspections and Testing

IRP Prior to pressure testing a supervisor shall walk the line to verify it is assembled correctly (e.g., components not installed properly, not enough swivels to allow movement of the line).

IRP The Restraint Owner shall ensure the pipe restraint system is appropriately installed and anchored.

29.5.4 Pressure Relief and Emergency Shutdowns

This section provides guidance for pressure relief and emergency shutdowns used to prevent the overpressure of a component’s design rating. This section applies to piping components only and does not address pressure vessels.

IRP Pressure relief and emergency shutdown devices should be based on two strategies of primary and secondary de-pressuring as described below:

- Primary pressure relief is the use of pressure shutdowns such as electronic trips to shut down equipment.
- Secondary de-pressuring focuses on a pressure relief device or pressure relief component.
  - Pressure Relief Valve (PRV)/Pressure Safety Valve (PSV): These relief components will reclose once the pressure drops below the set point.
  - Pressure Relief Devices: Pressure relief devices do not reset or reclose such as a burst disk.

When pressure relief devices are activated, the release and de-pressurization can be significant if there is a large amount of stored energy; the associated hazards have to be captured and controlled.

IRP During pressure pumping operations, every effort should be made to manage the pressures in real time within the implemented treatment pressure range, by using electronic sensors for emergency shutdown of equipment.

IRP All the associated equipment and parameters must be set within the Maximum Allowable Working Pressure (MAWP) of the surface and wellhead equipment.

IRP The pressure relief system shall be designed to protect the lowest rated component in the piping system.

29.5.4.1 Pressure Relief and Shutdown

IRP Consideration should be given to having more than one method of pressure protection such as the following:

- Establishing the working pressure during pre-job planning.
- Determining the lowest rated components in the system and ensure they are suitable for the working pressure (unsuitable components may need to be changed or the pumping or flowback plan modified).
- Identifying electronic and mechanical controls required for pressure relief.
- Setting electronic and mechanical controls as required within the limitations of the system.

Below are examples for how pressure relief settings are established in various scenarios. Multiple layers of protection are used to stop a pumping operation or vent off a vessel prior to an overpressure event. The examples provided below illustrate a hierarchy of control and are not intended to be prescriptive.

29.5.4.2 Pressure Relief - Hydraulic Fracturing Example

Table 10. Pressure Relief – Hydraulic Fracturing Example

kPa	Settings	Action
69,000	Maximum Allowable Working Pressure	Tolerance Range for Pressure Relief Activation
60,000	Pump Trip 2	
58,000	Pump Trip 1	
53,500		Treatment Pressure Range
51,300		

The pressure relief strategy for the hydraulic fracturing shown in Table 11 above is as follows:

- Treatment pressure range determines the overall strategy for the pressure relief system.
- The secondary protection for pump kick outs/shutdowns is determined. The pump kick outs are part of the pressure relief hierarchy; the true intent of a pump kick out is to provide a shutdown prior to relief through the pressure relief device.
- The Maximum Anticipated Operating Pressure helps determine the selection of the primary pressure relief device set pressure. It is important to remember that different styles of pressure relief devices have specifications on activation tolerances.

29.5.4.3 Pressure Relief – Well Intervention

Well interventions include acid stimulations, cementing operations, abandonments and the like. Interventions are much more complicated as the ability to match pumping equipment ratings to well pressure restrictions are not always possible. This means that pumping equipment pressure ratings may far exceed the components through which the equipment will be pumping. A thorough review of all components is required to set the Maximum Anticipated Operating Pressure. Table 12 is an example of a Well Intervention.

Table 11. Pressure Relief – Well Intervention

kPa	Settings	Action
35,000	Pumping Equipment Maximum Allowable Working Pressure	
21,000	Well Maximum Allowable Working Pressure (Surface/Downhole)	Pressure Relief Activation Tolerance
19,600	Relief Pressure Setting for PRD	
18,200		
18,000	Pump Trip	
17,300	Maximum Anticipated Surface Pressure	Treatment Pressure Range
13,800		

The pressure relief strategy for Table 12 above is as follows:

- In this example the Maximum Allowable Working Pressure (MAWP) is determined. This will set the strategy for the relief system.
- Equipment on location has a pumping Maximum Allowable Working Pressure of 35,000 kilopascals (kPa) and therefore the primary Pressure Relief Device (PRD) will have to be set at a lower relief pressure.

29.5.4.4 Pressure Relief – Well Testing

Well testing uses a combination of chokes and pressure staging to control higher pressures produced by the well for safe processing in lower pressure-rated equipment downstream. The following example illustrates a typical well testing application with a 9,927 kPa (1,440 psi) vessel.

Table 12. Pressure Relief – Well Testing

kPa	Settings	Action
9,927	Relief pressure setting for PRD	Pressure Relief Activation Tolerance
8,935	Simmer point setting for PRD	
7,942	Pressure Vessel High pressure shut down set point – typically 80% of Maximum Allowable Working Pressure	Secondary shutdown

The pressure relief strategy for Table 13 is as follows:

- In this example the Maximum Allowable Working Pressure of the vessel determines the set point for the PRD.

- The secondary shutdown device is set to 80% of the PRD to protect the vessel from nearing the MAWP.

29.6 Restraint Systems

Restraint systems are devices used to secure pipes and hoses, minimizing their movement in the event of temporary pipework failure. They are one of the controls used to mitigate the impact of such failures.

Following this IRP's recommended practices for the proper design and selection, handling and installation, and inspection and maintenance of restraint systems will help protect personnel, property and the environment.

Restraint systems are used in various applications involving different loads and environmental conditions. In some cases, restraints may last for years while in harsher conditions, they may degrade quickly. Restraints of different sizes, materials, or construction can also vary in durability within the same application.

IRP Restraints shall have a unique identifier for tracking usage, inspection, and maintenance.

The following figures provide examples of restraint systems.

Figure 35. Restraint System

Figure 36. Restraint System

Figure 39. Restraint System

Figure 37. Restraint System

Figure 38. Restraint System

Figure 39. Restraint System

Figure 40. Restraint System

29.6.1 Restraint System Design

The restraint system installed on a temporary piping system needs to be designed to handle the energy released during a catastrophic failure. It acts as a back up to other risk mitigation measures. As outlined in Section 29.3.5 Understanding Dynamic Forces Related to Restraint Design, when designing and selecting restraints, it is essential to consider the energy source (i.e., constant pressure or constant flow rate) and operating pressure differential.

Other considerations include:

- whether the fluid is compressible (e.g., gas, multiphase fluid) or incompressible (liquid, sub-cooled steam)
- the force exerted by the fluid jet discharged from the parted pipe (i.e., jet impingement force).

In constant pressure source scenarios (Wellbore Model), theoretical assessments and experimental work has found that incompressible fluids produce higher steady state thrust forces than compressible fluids. Due to this finding, the maximum thrust coefficient for incompressible fluids is 2.0 and for compressible fluids is 1.26.

> **Note:** See Appendix F: References and Resources for references to these theoretical assessments and experimental work.

IRP An engineering assessment should be performed and documented to justify the use of a lower thrust coefficient ($C_t < 2.0$) for compressible fluids flows to ensure conservative restraint design.

IRP For constant flow rate scenarios (Pump Model), the thrust force equation applies only to incompressible fluids. Restraint design in these cases should focus on impulse loading due to the incompressible flow. Any application involving compressible flows should be treated as a constant pressure source scenario (Wellbore Model).

In pipe break situations, the jet impingement force ($F_{Imp;}$ See Figure 2) may increase the load on the restraint. However, sensitivity analyses show that jet impingement generally has little impact compared to fluid jet thrust forces, so it can often be ignored when calculating the restraint design force. See C-FER File: G310 Final Letter Report: Assessment of Restraint System Dynamic Loading in High-Pressure Temporary Pipe Installation Break Scenarios on Energy Safety Canada’s website.

Typically, there are multiple parties involved in the successful design and application of restraints on temporary pipework systems. The Restraint Owner could be the OEM restraint manufacturer, a service company that provide restraints for use with their temporary pipework, a third-party rental company or the prime contractor. Within industry, there are examples of purchasing and qualifying a restraint system using multiple products and products that have not been specifically designed as a restraint..

IRP The Restraint Owner shall

- ensure the restraint system is designed according to this IRP, with documentation verifying it meets the application's loading requirements,
- install, replace, and maintain restraints according to the Original Equipment Manufacturer's (OEM) recommendations and the Restraint Owner's internal documentation.

IRP If the Restraint Owner assembles a system using products from non-restraint or restraint OEM sources, they shall calculate, evaluate and document the compatibility of those products as part of the restraint system. These systems shall be authenticated by a competent professional engineer.

29.6.2 Restraint Force Equations

The sections below provide the restraint force equations for the force on a restraint in a constant pressure source scenario (wellbore model) and in a constant flow rate source scenario (pump model) respectively.

IRP The manufacturer shall provide the appropriate specifications for the restraint so that end users can accurately assess if the restraint can withstand the predicted forces and is suitable for the intended application.

IRP The restraint manufacturer shall consider the performance of the restraint in both the hot and cold weather conditions that can be expected in Canada.

IRP The end user shall select the appropriate restraint for their piping application taking into consideration the restraint product materials, construction and performance under high strain rates.

Since there are many different factors and potential scenarios involved in establishing the maximum restraint forces that could develop in a particular application, it may be prudent to complete selected sensitivity analyses as part of the design process. Refer to Appendix B: Restraint Force Equation Theory and Examples, for further details and examples of completed restraint force calculations.

29.6.2.1 Force on a Restraint in a Constant Pressure Source Scenario

For restraint design and selection in a constant pressure scenario, it is assumed that the maximum force that will be applied to the restraint can be calculated as follows:

Equation 3. Force on a Restraint in a Constant Pressure Source Scenario (Wellbore Model)

$$F_{restraint} = F_{thrust-CP} = 2\, P_{AOF}\, A$$

where

$F_{restraint}$ **(Force on a Restraint)** is the sustained force applied to the restraint as it reacts to the thrust force imposed on the attached pipe segment in an incompressible flow situation (i.e., with $C_t = 2.0$), measured in Newtons (N).

$F_{thrust\text{-}Cp}$ **(Constant Thrust Force)** is the constant thrust force applied to the pipe while flow continues from the steady-state pressure source, measured in Newtons (N).

P_{AOF} **(Maximum Wellhead Pressure under Absolute Open Flow)** is the maximum wellhead pressure that can be expected to occur under sustained Absolute Open Flow (AOF) conditions for the well in question, or the maximum operating pressure of the tank if the flow originates from a surface vessel, measured in Pascals (Pa).

A **(Cross Sectional Flow Area of Pipe)** is the cross-sectional flow area of the pipe, measured in square metres (m^2).

While it is recognized that transient loading conditions will also occur immediately following the pipe break in this type of scenario, it is the steady state conditions that are used in the design calculations.

IRP Lower thrust coefficients should only be used after a competent engineering assessment for the specific installation or operation. It no assessment is available, the thrust coefficient of 2.0 should be applied for all constant pressure source applications, including both incompressible and compressible flow situations.

29.6.2.2 Force on a Restraint in a Constant Flow Rate Source Scenario

In the case of a constant flow rate source scenario (Pump Model), the maximum force on a restraint can be calculated using the following formula in Equation 4 (i.e., applicable only to incompressible flow conditions):

Equation 4. Force on a Restraint in a Constant Flow Rate Source Scenario (Pump Model)

$$F_{restraint} = F_{thrust-CF}\, \Delta t_{thrust} \sqrt{\frac{k_{restraint}}{m_{pipe} + m_{fluid}}} = \frac{\Delta P A L_{pipe}}{a} \sqrt{\frac{k_{restraint}}{m_{pipe} + m_{fluid}}}$$

$$F_{thrust-CF} = \Delta P\ A$$

$$\Delta t_{thrust} = \frac{L_{pipe}}{a}$$

where

$F_{restraint}$ **(Force on a Restraint)** is the force applied to the restraint as it reacts to the energy imparted by the thrust force impulse to the attached pipe segment, measured in Newtons (N).

$F_{thrust\text{-}CF}$ **(Thrust Force)** is the maximum thrust force applied to the pipe immediately after the break occurs in a constant flow rate scenario, measured in Newtons (N). The thrust force on the pipe in the Pump Model scenario is simply the assumed maximum pressure inside the pipe multiplied by the cross-sectional flow area of the pipe.

Δt_{thrust} **(Time Thrust Force is applied to the Pipe)** is the amount of time the thrust force is applied to the pipe, measured in seconds (s). The amount of time the thrust force is applied to the pipe is dependent on the length of the pipe segment and the speed of sound in the fluid within the pipe.

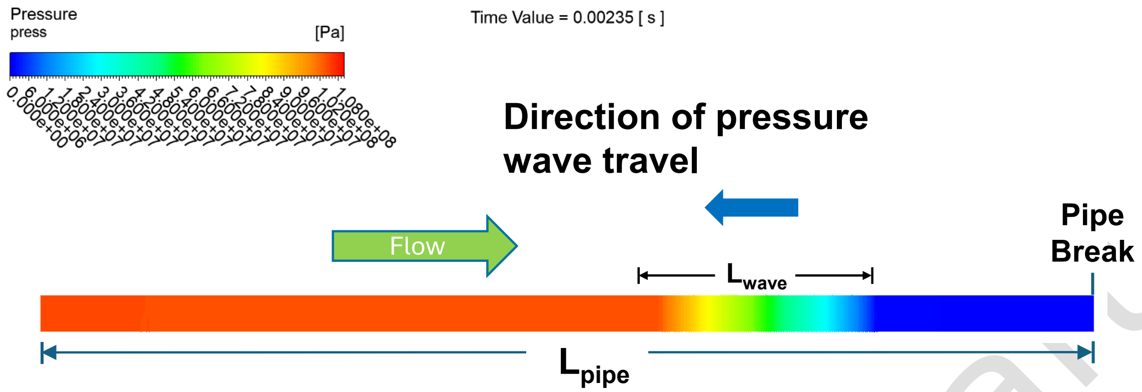
ΔP **(Change in Pressure)** is the maximum operating pressure of the pipe minus the atmospheric pressure (this is equal to P_{pump} at gauge pressure), measured in Pascals (Pa). see Section 29.3.5.

A **(Cross Sectional Flow Area of Pipe)** is the cross-sectional flow area of the pipe, measured in square metres (m^2).

L_{pipe} **(Length of Pipe)** is the length of the straight unanchored pipe segment that will move when subjected to the transient thrust force, measured in metres (m). The pipe length, L_{pipe}, is an important factor that needs to be defined in the design of the restraint system since it has a substantial impact on the restraint force magnitude in a constant flow rate scenario. This is because the pipe length directly impacts both the duration of the thrust force impulse, which acts to accelerate the pipe segment, as well as its total mass.

When the pipe parts, the piping system will immediately start to depressurize to atmospheric pressure. As shown in Figure 41, the depressurization starts at the break point and a pressure wave travels at the speed of sound in the fluid down the inside of the pipe away from the break. The pressure wave will travel throughout the pipe system all the way to the pump pressure source (a similar pressure wave will also travel through the pipe on the opposite side of the break toward the well).

Figure 41. Direction of Pressure Wave Travel vs. Direction of Fluid Flow



From the perspective of the thrust force impulse which acts on the pipe, the relevant segment length corresponds to the unanchored length of straight pipe extending from the break (i.e., the section of pipe that is assumed to be free to move under the thrust impulse loading). Typically, for restraint design, the longest straight section of unanchored piping will be selected for this parameter (e.g., it can be measured from the assumed break point at the end of the straight segment to the first change of direction in the piping such as at an elbow or chicksan). The duration of the force impulse corresponds to the time required for the pressure wave to traverse this straight pipe segment. Therefore, the longer the straight section of pipe, the longer the thrust force will be applied to the pipe.

α **(Speed of Sound)** is the speed of sound in the fluid, measured in metres per second (m/s). The pressure wave travels at the speed of sound in the fluid when the pipe breaks. For example, in the case of a 10 m section of pipe filled with fresh water at room temperature which parts at 103.4 MPa, it would take only 0.0066 seconds for the pressure wave to travel the full 10 m distance. With the same conditions in a 50 m section of pipe, the duration would be five times longer. In each case, this represents the time over which the thrust force impulse is applied to the pipe segment (Δt_{thrust}).

The speed of sound is a function of fluid density, decreasing with lower density fluids. However, as a default, one can use the speed of sound in fresh water at room temperature in their design calculations (i.e., 1,481 m/s at 20°C).

$k_{restraint}$ **(Restraint Spring Constant)** is the restraint spring factor or stiffness coefficient, measures in Newtons per metre (N/m). The restraint spring constant (or stiffness coefficient) reflects the rate at which the restraint absorbs energy as a function of its elongation. In a pipe break situation, the restraint is expected to effectively absorb substantial energy over a very short period (i.e., milliseconds).

Traditional restraint testing and qualifying has been performed using bench tests which load the restraint samples at low strain rates (stretch rates), which are not necessarily comparable to the loading rates that the restraints would experience in a pressurized temporary piping system failure situation. The restraint manufacturer is responsible for understanding the ability of the restraint product to withstand such dynamic loading conditions.

***m_{fluid}* (Mass of the Fluid)** is the total mass of the fluid contained within the selected pipe segment, measured in kilograms (kg).

***m_{pipe}* (Mass of the Pipe)** is the total mass of the straight unanchored pipe segment that will move when subjected to the transient thrust force, measured in kilograms (kg). Typically, the mass of fluid (m_{fluid}) contained within the selected pipe length will also be included in the calculation since it contributes to the total mass acted upon by the thrust force impulse.

IRP One should not assume the thrust force applied to the pipe (i.e., $F_{thrust\text{-}CF} = \Delta PA$), will have the same magnitude as the force exerted on the restraint in a constant flow rate scenario - the restraint force is a function of the energy imparted by the thrust force impulse to the pipe segment.

IRP For restraint design, when deriving the restraint force in a Pump Model scenario, one should use the maximum anticipated operating pressure that can be expected during operation of the piping system or the rated maximum allowable working pressure of the temporary pipework system.

IRP The end user should consider the maximum unanchored length of straight pipe where a break could occur in the design of the restraint.

29.6.3 Pre-Rig In

IRP The following should be checked before installation of the restraint system:

- In-service date is current
- Restraints are suitable for the expected temperature conditions (e.g., cold weather ratings on shackles/clevises or synthetic fibres, temperature of the pumped material)
- Load ratings (as shown on restraint tags) meet or exceed the potential forces that the restraint system could experience
- Restraints are undamaged per the OEM specifications. (see 29.6.5.3 Inspection Criteria)
- Hardware (e.g., shackles/clevises) has all necessary and appropriately sized components installed (e.g., safety pins, r-clips, nuts) and are undamaged

IRP These checks should be performed by someone familiar with the restraint system and operational requirements of the job.

IRP Hardware and restraints shall not be used for purposes other than their designed scope.

See Appendix D: Checklists, for a sample pre-job inspection checklist.

29.6.4 Installation and Make-Up

IRP A restraint system shall be installed by competent personnel familiar with the manufacturer specifications for the installation of the system.

IRP All company Standard Operational Procedures (SOP), safety procedures and guidelines shall be followed during installation.

IRP Each piping section or line from start to finish shall be restrained by the same brand of product and anchored on both ends.

> **Note:** Mixing restraint systems this way may not meet the pressure requirements of the operation and can reduce the integrity of the overall restraint system's capacity to handle pressure.

IRP The following should be confirmed during installation of the restraint system:

- Installation of the restraints does not interfere with operations (e.g., half-hitches or spines do not interfere with the operation of valves)
- Ribs are present on all connections and across each segment of the swivel, if using spine and rib method
- Restraint system has adequate tension and no excessive slack
- Restraints are anchored appropriate to the application (see 29.7 Anchor Points)
- Installation of the restraint system is as per manufacturer specifications

See Appendix D: Checklists for a sample installation inspection checklist.

29.6.5 Post-Installation Inspections and Testing

The two types of post-installation inspections for restraints are as follows:

- Frequent usage inspections
- Periodic inspections

IRP If the restraint is exposed to any type of leak, it shall be inspected for damage.

IRP Any restraint involved in an unplanned release or shock loading event shall be inspected and may require load testing (as per OEM/supplier criteria) if it is not replaced.

29.6.5.1 Frequent Usage Inspections

The frequent use inspection is similar to the installation inspection (see 29.6.4 Installation and Make-Up). It is a visual inspection for things like damage from pinch points or vibration, tightness or loose pieces.

IRP Inspections shall be performed by competent personnel (i.e., familiar with visual inspection criteria).

IRP A visual inspection for damage shall be performed daily or during each shift if there are multiple shifts per day.

Written records are not required for frequent inspections.

29.6.5.2 Periodic Inspections

Periodic inspections are detailed inspections and may include load testing if specified by the OEM.

IRP Monthly, quarterly or bi-annual periodic inspections should be considered for high-use restraints or severe conditions (i.e., abnormal operating conditions).

IRP Periodic inspections shall

- be performed by competent personnel,
- be performed annually, at a minimum,
- be based on the criteria defined by the OEM and/or supplier,
- include a complete inspection for damage to the restraint (see Table 14 Restraint Inspection Criteria),
- include written records documenting the inspections and tests performed (e.g., load test).

IRP Each restraint shall be examined individually, taking care to expose and examine all surfaces.

IRP The inspection shall be conducted on the entire length of the restraint, including splices.

Magnification may be required.

IRP Written records of all periodic inspections shall be maintained.

Load testing may be required depending on the type of restraint used, the operational conditions and the OEM recommendations.

IRP Post-inspection load testing should be completed as per manufacturer's recommendations and to a reasonable load based on the maximum for the restraint.

29.6.5.3 Inspection Criteria

IRP The criteria in Table 14 shall, at a minimum, be checked during a frequent or periodic inspection.

Note: This is not an exhaustive list. Manufacturer recommendations need to be followed.

Table 13. Restraint Inspection Criteria

Criteria	Notes
Missing or illegible restraint identification	• Working pressure • Flow line type and size • In service date • Serial numbers • Manufacturer
Abrasion, excessive wear or holes	• Most external abrasion is localized. • This may present as cut and/or frayed fibers. • Damage sufficient to degrade the restraint is usually obvious. • Jacketed restraints will show excessive wear on the sheath. The load bearing core should not be exposed
Cuts, tears or broken strands	• It is usually obvious where fibers have been cut, broken or torn sufficiently to degrade the restraint. • The severity and frequency of the cut(s) require the inspector to determine whether to remove the restraint from service. • For jacketed restraints where the jacket is not load bearing, a cut that does not expose the core probably doesn't degrade functionality. • Cuts to jackets may cause other adverse effects such has handling difficulties and inability to apply appropriate installation techniques.
Snags	• Individual strands and yarns can be snagged and pulled out or away from the restraint structure and construction. This can create uneven load bearing of fibers on the affected area of the restraint.
Chemical damage or discoloration	• Synthetic restraints can be weakened by chemical exposure with various fibres reacting differently.
Burns, melting or charring	• Melting, bonding of fibres and/or brittleness may be observed as a result of heat damage. These manifestations are not always present and, in some cases where present, may not affect the restraints effectiveness.

Criteria	Notes
Splice damage	• Ensure eye splices and end-to-end splices are as per OEM specification/instruction.
Loose or broken stitching	• Stitching may be present at termination eyelets or connections of material or fiber. Ensure stitch patterns, frequency and stitch density are as per OEM or supplier recommendations.
Evidence of crushing or stretching that compromises tensile strength	• Crushing and stretching will affect the cross-section diameter of the restraint. This can lead to a weak section of the restraint and a degrade strength.
Foreign matter that has permeated the rope	• Foreign matter such as dirt, sand and gravel can create internal abrasion and affect the tensile strength of the restraint. Examine each restraint for internal abrasion.
Unintentional knots	• Unintentional knots can affect integrity of the restraint.

IRP Ropes with unintentional knots shall not be used unless the working load is reduced by an appropriate factor based on 50% of the published rope strength unless specific data/testing is available to support the continued use of the rope.

IRP Rope shall be retired if knots cannot be removed without causing structural damage to the restraint.

29.6.6 Maintenance, Storage, and Transport Requirements

IRP Any restraint that is altered in any way shall be load tested to OEM/supplier specifications.

IRP Restraint system maintenance shall be performed by competent personnel and based on specifications of the OEM and/or supplier.

IRP Restraint system storage, transport, and handling shall be in accordance with the specifications of the OEM or supplier.

29.6.7 Potential Hazards

The following are potential hazards associated with the restraint system:

- Damage to the restraint system can lead to restraint system failure.
- Incorrect installation or operation of the restraint system can lead to restraint system failure (e.g., driving over restraints, pinch points, exposure to chemicals, mishandling).

- Connecting restraint systems of different pressure ratings may not meet the pressure requirements of the operation and can lead to restraint system failure.
- Use of non-sanctioned hardware to connect the restraints or to connect to an anchor point.
- Restraint system failure can lead to injury, property damage or environmental damage.

29.6.8 Basis for Retirement

The basis for retirement establishes the parameters for removing a restraint from service.

IRP The supplier shall establish a basis for retirement for each specific restraint type.

IRP The basis for retirement must consider local jurisdictional regulations for restraint systems.

IRP The basis for retirement shall consider OEM/supplier specifications, shelf life and conditions of use.

IRP The restraint should be removed from service if there is any doubt as to its reliability.

IRP Restraints shall be removed from service if continued use may result in a hazard (see 29.6.9 Potential Hazards).

IRP Restraints initially removed from service (e.g., during a pre-rig in inspection in the field) shall not be returned to service unless approved by a competent person.

Residual strength in a used restraint can only be estimated by destructive test methods (e.g., load testing).

29.7 Anchor Points

Anchor points absorb the forces transmitted by the restraint system, when a temporary pipe fails.

Multiple temporary pipes of various sizes may be used, each with its own restraint system and each requiring specific anchor points.

IRP The anchor point's rating shall be established by a professional engineer or competent person.

IRP Anchor points shall have a rating that meets or exceeds the restraint system's requirements.

IRP Service providers, owner and/or Prime Contractors shall identify anchor points for the temporary pipework or final restraint termination.

IRP The location of anchor points should be considered during lease set up and lease inspection to ensure they are not placed in high traffic areas.

It is important to consider the positioning of anchor points in the overall surface layout, such that it eliminates or minimizes risk exposure to persons and property. Other safety measures such as safety zones and boundaries can be used to control risk exposure.

The following figures are examples of various rated anchor points.

Figure 42. Coil Tubing Trailer Frame Mounted Anchor Points

Figure 43. Coiled Tubing Reel Mount Anchor Point

Figure 44. Nitrogen Pumper, Welded on Anchor Point, Top of Frame

29.7.1 Requirements

IRP The anchor point's load rating should be readily identifiable and accessible on a data plate to allow the end user to easily access and understand this information.

IRP Anchor points should be single-purpose only.

29.7.2 Inspections

Anchor points require regular inspections to ensure they remain functional even if they haven't experienced a load. Factors such as age, corrosion, or wear may affect their ability to serve as anchor points.

IRP Anchor points shall be inspected periodically and/or after they have sustained a load, and before use to ensure they are in good condition. Inspections shall follow the manufacturer's instruction and be performed by a competent person.

IRP After sustaining a load, anchor points must be removed from service until they are inspected, repaired, or reauthenticated. Any damaged or deteriorated anchor points must be replaced or repaired and reauthenticated by a professional engineer or competent equivalent.

29.7.3 Connecting Anchor Point to Restraint System

The Restraint Owner is responsible for connecting their restraint system to an anchor point, ensuring it functions correctly.

IRP The Anchor Point Owner shall communicate the anchor point's rating to the Restraint Owner, and both shall ensure proper attachment.

IRP Restraint Owners shall specify connection requirements and necessary hardware for the restraint system. Any modifications shall be reviewed and authenticated by a Professional Engineer.

29.7.4 Anchor Point Selection

Selecting anchor points is essential to the restraint system design. Without proper anchor points at both ends of the temporary pipe system, the system is incomplete. Additional anchor points may be used in high-risk areas to prevent pipe movement. Overall, anchor point selection requires careful consideration. Due diligence is required when considering using wells or wellheads as anchor points, taking into account well construction, history, and potential loads.

Wells in the Western Canadian Sedimentary Basin vary in design, age, and condition, each with specific risks that need to be evaluated when determining well integrity for use as an anchor point.

Connecting a restraint system to an anchor point introduce differences in load, equipment, or hardware requirements similar to a pipeline specification ("spec") break. These limitations need to be communicated to workers involved in installing, inspecting and certifying the system.

Anchor points may include the following:

- Mobile equipment with a rated anchor point
- Concrete blocks/skids with a rated anchor point
- Rated or pull tested ground anchor that can be rated or tested to meet the required rating of the restraint system

IRP **The Anchor Point Owner shall ensure the suitability of any anchor points on their own equipment.**

IRP **The integrity of the well is paramount. Anchoring to the well shall only be done if it can sustain the expected loads without compromising its integrity. Consider the following when using a well or wellhead as an anchor point:**

- Well and wellhead construction, including mechanical specifications
- Well integrity (e.g., corrosion, history, age)
- Cement integrity and placement
- Expected loads on the well or wellhead, under various operating conditions (e.g., bending moments, axial loads, wellhead pressure, temperature effects, bolt specs)
- Anchor placement on the well or wellhead (consider failure modes and weak points)

Note: Other conditions may be added as needed by the well owner.

IRP **The well owner shall verify if the well can be used as an anchor point and the decision supported by a site-specific risk assessment.**

Additional anchor point considerations include the following:

- Ground conditions (wet/soft, frozen/thawing, dry/loose, compaction, etc.)
- Practical and effective anchor point that will not interfere with adjacent work activities
- The angle at which the load would be transmitted from the restraint system to the anchor
- One anchor used for multiple restraint systems
- Bending moments imposed on the anchor
- Limitations or restrictions of the anchor point

IRP **All anchoring shall be done within the exclusion zone.**

29.7.5 Anchor Point & Hardware – Post Line Parting Incident

IRP **If a surface line parting event or an incident involving the activation of anchor points and hardware (e.g., uncontrolled pressure release) occurs, the restraint system, hardware, and anchors shall be taken out of service, tagged, and either replaced or reauthenticated by a Professional Engineer before being returned to use.**

IRP Paperwork shall be provided as proof of replacement or reauthentication.

IRP If the temporary pipework restraint system is activated due to a pipe failure, the entire system, including the hardware, shall be removed from service and reauthenticated or destroyed as per the OEM's guidance.

IRP Structural damage may extend beyond the anchor, so the entire load path should be inspected and replaced or reauthenticated.

29.8 Exclusion Zone

An exclusion zone is a predefined area with the potential for increased exposure to high-risk hazards where access is restricted to workers or limited to only trained workers. Some form of approval is required for workers to enter the exclusion zone.

Exclusion zones may already be within established, defined zones existing in documents such as company SOPs and technical procedures. Exclusion zone boundaries are based upon the type of equipment, piping, and hosing along with the fluid types and what the maximum working pressure applied will be. The movement range of the restrained surface lines is to be considered if a breech occurs, compromising the surface line assembly. Other safety variables such as pressure relief valves, check valves, barriers that offer additional layers of risk reduction and/or mitigation are also considered.

Exclusion zones may already be within established, defined zones existing in documents such as company SOPs and technical procedures. See Figures 45-49.

IRP Exclusion zones shall be defined and identified to all on-site personnel.

IRP Exclusion zone boundaries shall be determined based on a site-specific hazard assessment. When determining the boundary of the exclusion zone the fluid type needs to be considered during the site-specific hazard assessment.

- Examples of fluid types that will be pumped and the risks that each type will bring during pumping are:
  - fluids that change from a liquid to gaseous state, like nitrogen or carbon dioxide, will bring change in pressure and temperature variable to wherever in the pumping system.
  - Liquified gases, such as propane and natural gas. These behave like cryogenic fluids, but they also bring other risks like flammability and explosion.
  - Petroleum based products can be unrefined crude oil, synthetic oils, kerosenes, diesels and everything in between. Each will have its inherent dangers, such as explosion and flammability risks.
  - Chemical types and there are a wide variety of chemical types, that may bring risks to personnel and the environment if the surface lines breach. Each chemical type needs to be reviewed and assessed. E.g., Acid blends, caustic blends, alcohols (like methanol).

- Produced water can contain a variety of chemicals (spent or active), solids and bacteria to name a few variables. It is used repeatedly for many purposes such as diagnostic fracture injection tests, hydraulic fracturing, pump downs, drilling, and milling. Every sample of produced water will have different associated risks.

29.8.1 Approval to Enter an Exclusion Zone

It may be necessary to enter or pass through an exclusion zone during operations to perform short-duration tasks.

IRP There shall be a process in place to approve worker entry to the exclusion zone. This process shall include minimizing the number of workers entering the zone and the duration for which they are in the zone.

IRP The number of workers and frequency of which they enter or pass through the exclusion zone shall be kept to a minimum.

The process this approval takes will vary by site, Owner, Prime Contractor and/or Service Company and may depend on local jurisdictional regulations.

Figure 45. Exclusion Zone Fracture Operation Example

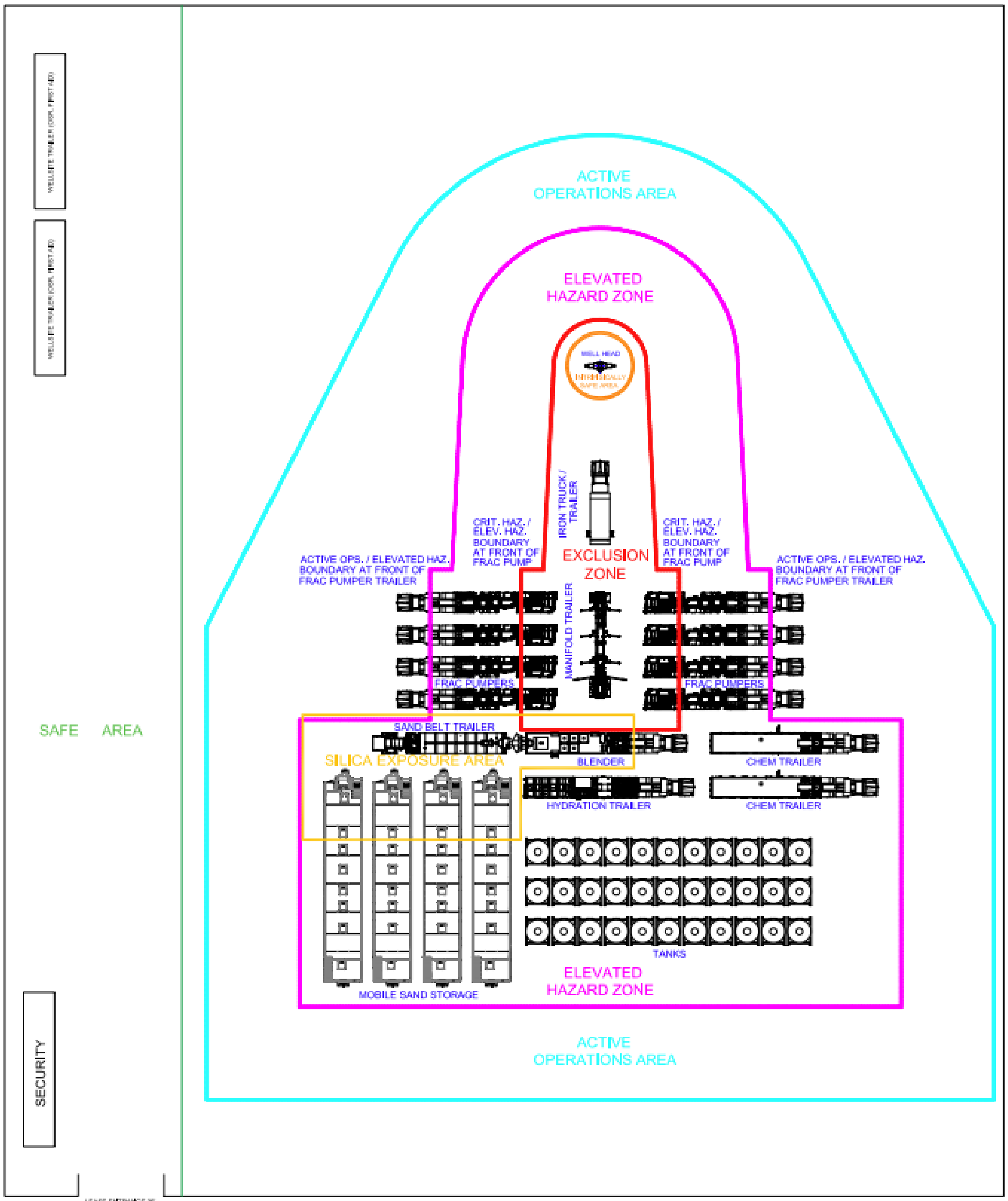


Figure 46. Exclusion Zone Coil Tubing Operation Example

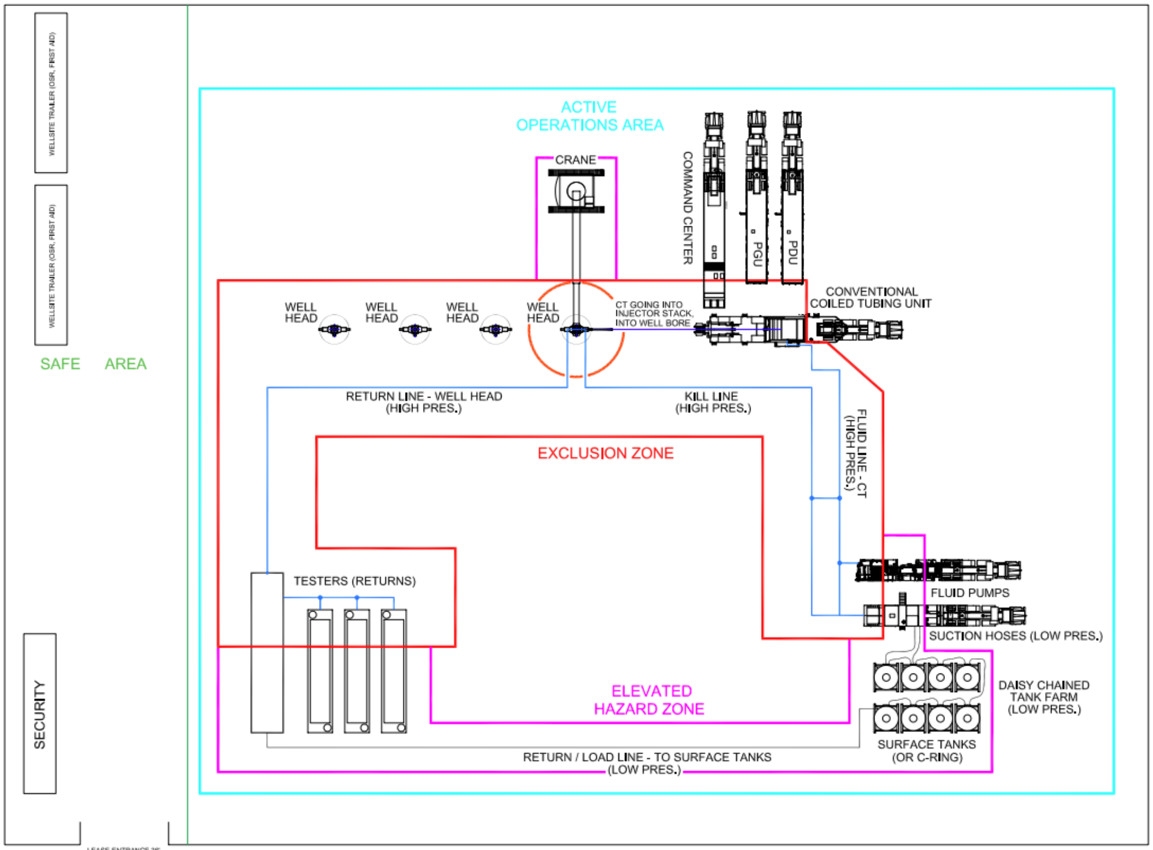


Figure 47. Well Testing Exclusion Zone Example

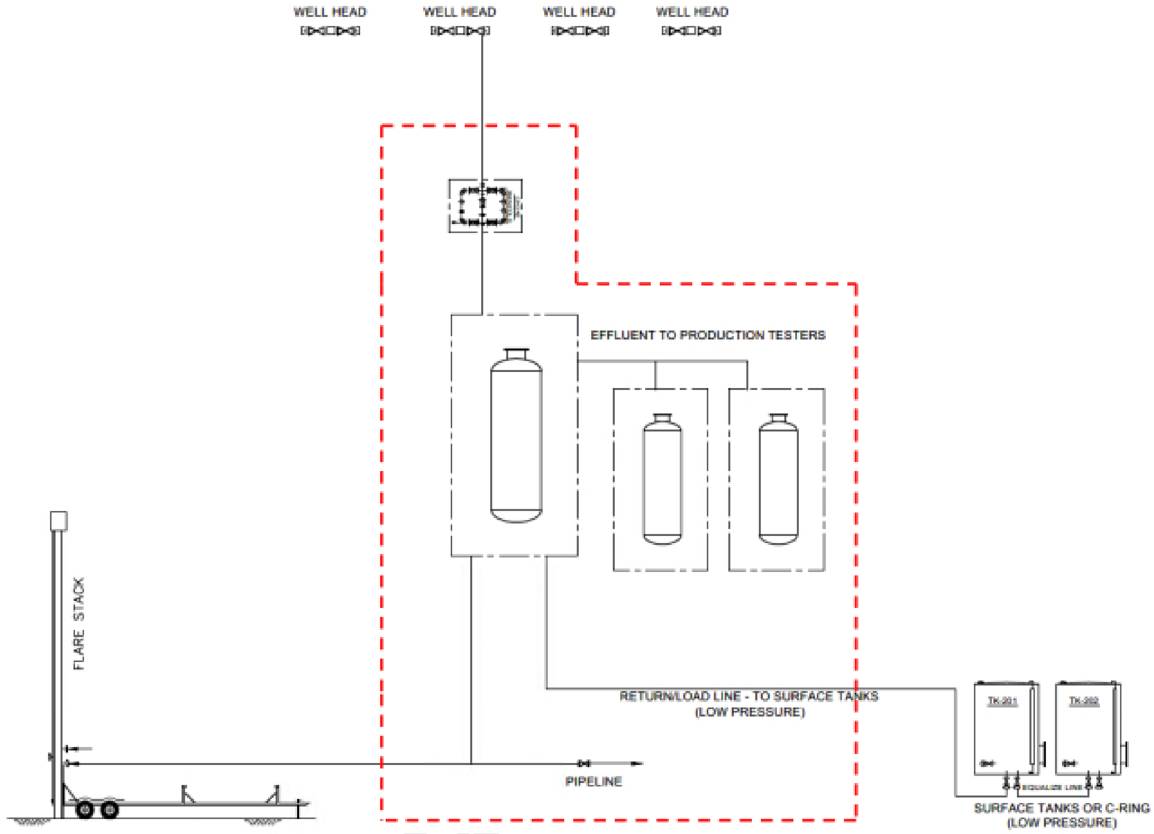


Figure 48. Service Rig Exclusion Zone Example

Figure 49. Service Rig Exclusion Zone Example

29.9 Pressure Testing

Pressure testing is a regulatory requirement to verify that the system's integrity is sufficient to proceed with operations.

IRP The temporary pipework system must be pressure tested before operation.

IRP Before pressure testing, the following shall be done:

- a supervisor shall walk the line to confirm it is assembled correctly (e.g., proper component installation, adequate swivels for line movement).
- The maximum pressure for the test shall be established, communicated, and shall not exceed the maximum allowable working pressure of the lowest-rated component (lowest working pressure)
- The over-pressure shutdown system (i.e., trips) shall be set according to the pressure limits of all surface equipment, as determined by the service supervisor in consultation with the Prime Contractor.

IRP Before pressure testing, the trips should be tested at a lower pressure determined by the service supervisor in consultation with the Prime Contractor.

IRP Temporary piping shall be pressure tested to 10% above the maximum anticipated operating pressure of the operation but not exceeding the maximum allowable working pressure of the lowest-rated component (lowest working pressure).

IRP In cold weather, temporary piping should be warmed before pressure testing.

IRP A pre-job safety meeting and hazard assessment must be conducted, documented, and communicated before pressure testing.

IRP At a minimum, the system should maintain the test pressure long enough to detect leaks and the pressure to stabilize. Test durations may vary based on local jurisdictional requirements or that of the Prime Contractor or Service Company.

IRP If temporary piping is disassembled and reassembled during operations, or between stages of an operation, the affected components shall be re-tested before use.

29.10 Disassembly

Consider the following when disassembling the pipework system:

- Obtain proper authorization to shut in and de-pressurize.
- Ensure all pressure sources are isolated.
- Confirm there is no conflict with simultaneous operations.
- Inspect the line to ensure all valves are in the correct position and the line is fully depressurized.
    - Confirm there is no trapped pressure.

  Note: Be aware pressure can be trapped within valves.

- Remove and inspect restraints for damage or defects and mark any damaged or defective restraints as out of service. Contact the manufacturer for recommended recertification or reassessment requirements.
    - Store restraints as per OEM specifications.
- Inspect piping for damage or defects and mark any defective or damaged pipe as out of service. Contact the manufacturer for recommended recertification or reassessment requirements.

29.11 Water Transfer Systems

Water transfer lines include layflat hoses or rigid pipes, commonly made from materials like thermoplastic polyurethane and nitrile, along with any supporting equipment. These components are covered under the scope of this document.

> **Note:** Fire hoses and high-density polyethylene lines are out of scope for this document.

29.11.1 Pre-job Planning

Water transfer jobs can range from simple to complex, covering on-lease operations or spanning multiple kilometers, crossing roads, rivers, and dealing with significant elevation changes.

IRP The Operator and Service Provider should work together to create a pre-job plan.

Key considerations in the planning process include the following:

- The type of product being transferred, including expected rates and pressures
- Route selection, terrain, environmental conditions, weather, and total distance
- Type of piping or hoses used
- Fluid sourcing and delivery points (e.g. from ponds, rivers, or tanks)
- Pump placement and elevation changes
- Hydraulic analysis requirements
- Impact on residents, businesses, and the environment

The objective of water transfer system design is to prevent spills and ensure safety for all involved. Proper planning ensures safe and efficient execution, helping maintain good relationships with residents, regulators, and businesses.

IRP The Owner and/or Prime Contractor must ensure thorough planning and implementation of all safety measures for water transfer operations, prioritizing safety of the workers, environment and the public.

29.11.2 Route Selection

IRP The Owner and/or Prime Contractor should choose the most direct route while considering the following:

- Avoid unnecessary elevation changes and rough terrain.
- Avoid exceeding the minimum bend radius.
- Minimize road and water crossings.
- Avoid sensitive areas, side slopes, and natural or manmade hazards.
- Minimize the impact of noise, light pollution, and increased traffic on surrounding areas.
- Minimize the impact on local water drainage to prevent excessive water accumulation due to pipeline routing. Using culverts for crossings is acceptable, but they should not obstruct existing drainage patterns.
- Determine how equipment will be drained, especially in low lying areas.

IRP Water transfer lines shall not be partially or fully submerged in any body of water that is not the source.

IRP A leak detection method shall be in place.

29.11.3Water Transfer System Design

Water transfer systems can become complex due to high horsepower pumps, specification ('spec') breaks, multiple connections, long distances, hydrostatic fluctuations, freezing conditions, pigging operations, line fill and many other factors.

IRP A competent person or a professional engineer should ensure the system is designed correctly and changes are managed through a diligent change management process. Engineering judgement should prioritize primary containment and safety for workers, the environment, and the public.

IRP For high-risk areas or complex systems, a hydraulic analysis shall be performed by a competent person or professional engineer.

Low elevation points are subject to increased hydrostatic pressure and a higher risk of overpressure events that can cause injury, death, or loss of containment.

IRP Low elevation areas should be identified and all necessary precautions should be taken to mitigate risks and ensure system integrity.

IRP The hydraulic analysis report should be reviewed by the owner and/or prime contractor (i.e. operator). See 29.11.4 Hydraulic Analysis Report.

Water transfer projects can undergo many changes throughout their lifecycle due to dynamic operating conditions, such as start-up, fill-up, static conditions, changing flow rates, winter operations and pigging operations. These conditions can lead to pressure changes in the line, such as line creep, which may displace equipment, shift the line into unsafe positions, or put undue stresses on equipment and couplings, thereby compromising integrity.

Significant pressure fluctuations can also occur during pigging and fill operations, if not properly planned. Therefore, conducting a hydraulic analysis, implementing a robust change management process, and continuously monitoring the line are essential for safe and efficient water transfer operations.

IRP A line operating plan should be in place to continuously monitor equipment and operating parameters as conditions change. This includes, but is not limited to, monitoring for line or equipment displacement, equipment stress, and ensuring operations stay within the Maximum Allowable Working Pressure (MAWP) of the system.

29.11.4 Hydraulic Analysis Report

IRP A hydraulic analysis report should include the following details:

- Route selection with topography and elevation changes
- Maximum allowable working pressure (MAWP) of the system
- Maximum anticipated operating pressure (MAOP) of the system
- Expected and maximum allowable flow rates
- Expected pressure along the route under normal operating and static conditions (no flow)
- Location of pumps along the route
- Identification of all equipment along the route with pressure and flow rate limitations
- Road crossings and equipment used at these crossings
- Identification of sensitive areas along the route
- Pigging equipment, operations, and limitations

IRP At all times during the job, pressure on the system shall remain below the Maximum Allowable Working Pressure (MAWP) of the system including startup, shut down, normal operations, and static and non-routine conditions.

IRP MAOP shall not exceed MAWP.

IRP A process flow diagram should be considered in the design process to show system connections, specification (spec) breaks, outline equipment specifications (sizes and pressure ratings), provide guidance on restraint systems, and indicate the placement of pressure relief valves (PRV’s).

29.11.5Equipment Selection & Design

29.11.5.1 Road Crossings

IRP Road crossing design and maintenance should include the following criteria:

- Ensure adequate flow for the piping system.
- Maintain structural integrity to handle the expected loads of traffic and provide vehicle clearance.
- Limit interference with traffic flow while providing sufficient distance near intersections for safe turns without increasing collision risks.
- Match the width of the road for optimal road crossing dimensions.
- Establish a regular inspection frequency to maintain the road crossing's integrity and prevent progressive traffic disruptions.
- Install signage to alert vehicles to the presence of a road crossing throughout the duration of the project.

29.11.5.2 Material Selection

Some operators and service companies may choose to move fresh or produced water through the layflat hose or rigid piping.

IRP Before transferring produced water through layflat hoses or rigid piping, the OEM should be consulted for the proper material selection. Additionally, any contaminants in the produced water that could impact the integrity of the layflat hose or rigid piping, and couplings should be disclosed to the OEM.

29.11.5.3 Couplings

Typically, the layflat hose is the weakest part of the hose system, not the coupling. The most common failure point is where the layflat hose connects to the coupling. Field repairs can be made by cutting out the damaged portion of the hose and reattaching it to the coupling.

IRP Pump connections should be monitored during start-up to detect excessive stress on the equipment and reduce the risk of catastrophic failure.

Line creep and the weight of the water transfer line can induce excessive stress on the connection due to bending moments or axial stresses if not adequately supported or accounted for.

29.11.6Risk Management

29.11.6.1 Modes of Failure for Temporary Layflat Hose System

Industry has observed many temporary water transfer line failures in recent years, emphasizing the need to understand their root causes and apply mitigations to ensure worker and public safety. Injuries have occurred around the pumps, particularly on the discharge side. Common causes of these failures include the following:

- Workers positioned in the line of fire
- Operating at pressures exceeding design limits
- Incorrect assembly of connections or hoses to couplings
- Unidentified and unmanaged specification breaks
- Poor communication and lack of competency
- Using improper tools or not following procedures when moving water transfer lines
- Exceeding equipment load limits (i.e. not accounting for bending or axial stress)
- Line creep due to expansion under various operating conditions

IRP To protect workers and the public, safety mitigations should be assessed through a risk-based approach. Potential safety measures include the following:

- Establishing exclusion zones in high-risk areas, such as around pump discharge and spec breaks, especially during start-up operations when stress on the line could lead to unexpected failures.
- Installing visible barriers and signage to warn of danger in exclusion zones.
- Placing pump controls in lower risk areas, such as the suction side.
- Installing PRV's on the discharge side of pump(s) to prevent deadheading events (i.e., Running pumps full of liquid while the outlet valves are closed).
- Installing a restraint system in areas frequented by workers.

29.11.6.2 System Integrity Verification

Most water transfer operations are unable to confirm the integrity of the assembled system through conventional pressure testing, therefore a leak inspection is used to verify the integrity. Therefore additional protective measures are essential to safeguard workers and the environment.

IRP The initial leak test should be conducted with freshwater (i.e., non-saline surface water, drinking water, or treated effluent).

IRP The water transfer equipment is put into service and monitored for failures, therefore other mitigation measures should be put into play to protect the workers in the area and the environment.

IRP Hydraulic leak inspection shall be conducted throughout the entire water transfer system.

IRP The owner and/or prime contractor shall identify potential areas where overpressure or abnormal pressures could occur. The operator shall evaluate the risks and establish safeguards against overpressure while protecting workers and the public who could be exposed to the hazards in these areas.

IRP Pumps along the route shall have pressure monitoring devices installed on the discharge side and in any areas sensitive to overpressure (e.g., where elevation changes could increase hydrostatic pressure or at choke points) to closely monitor pressure levels.

IRP Discharge pressure should be monitored from a safe location to minimize the risk to workers in the event of failure.

29.11.6.3 Water Transfer Restraint Systems

IRP Restraint systems for water transfer should be designed in collaboration with the service provider and OEM.

While restraint systems cannot prevent catastrophic failures, they are intended to limit equipment movement and reduce the risk of injury or death.

IRP Proactive measures should be implemented to prevent catastrophic failures from occurring in the first place, including but not limited to the following:

- Conducting a hydraulic analysis of the operation
- Safeguarding against pipe separation (e.g. overpressure protection)
- Ensuring competent personnel oversee system design and operation
- Selecting appropriate equipment
- Establishing a robust management of change protocol

IRP The owner and/or prime contractor should use a risk-based approach to implement mitigations against catastrophic failures and determine the placement of restraint systems on water transfer lines. Additionally, exclusion zones should be established in high-risk areas.

IRP Where high traffic areas interact with the public, proper warning signage should be installed.

IRP Service providers and layflat hose system owners should educate their workforce about the risks associated with layflat hose systems, even though the pressures may be lower than other parts of the industry. It should be communicated to workers that even though the pressures on these lines may be small relative to high-pressure treating iron on a hydraulic fracturing operation, the large diameter of the hose can store significant energy and could still cause injury or death if a failure were to occur.

The preferred method for restraining layflat hose is to use synthetic fibre type restraint systems as steel cables lack the flexibility needed to effectively choke and grab the hose.

IRP Restraint systems shall be installed as per OEM recommendations.

29.11.6.4 Layflat Hose Inspection and Repair

Wear and tear on layflat hoses may lead to failures, requiring either repairs or retirement from service.

IRP The service provider should implement a hose inspection and repair program.

IRP The inspection program should include the following:

- Outline the minimum inspection frequency.
- Identify key areas to inspect that are prone to wear and tear or common failure.
- Outline conditions under which the hose should be retired from service.

IRP All repairs shall be done in accordance with the OEM's recommended procedures and the personnel making the repairs shall be competent.

IRP Layflat hose, couplings and associated equipment should be visually inspected to ensure no defects are present and for proper assembly before operation.

29.11.6.5 Line Fill and Purge/Pigging Operations

Line-filling and purging operations are some of the riskiest operations in water transfer projects. Therefore, operators and service providers should have good procedures to perform these operations safely.

IRP System limitations during pigging operations shall be considered during the design stage of the project.

IRP Pigging equipment should be accurately sized with suitably rated connections for service.

IRP Pigging equipment shall be sized and rated for the expected pigging pressures, with appropriate shutdowns to prevent over-pressuring of the system.

IRP The hose assembly being pigged should be securely anchored to prevent uncontrolled movement and not left open-ended or unrestrained.

IRP Pressure during pigging operations should not exceed Maximum Anticipated Operating Pressure of the water transfer system.

Key risks to consider during line filling operations include the following:

- Line movement, could put more stresses on the line and could move into the line of fire
- Air discharge, which can cause pressure changes in the line or could observe jacking on pumps as air circulates through the pumps
- Solids exiting lines at slush points (i.e., ice in the line) during winter operations
- Filling a line too fast could compress air and cause line to overpressure and fail

IRP Proper line filling procedures should be followed to prevent overpressure and line failures.

Key risks to consider during purging operations include the following:

- Knowing positioning of the pig relative to inline pumps, such that pigs do not enter the pumps
- The pressure on the line during purging operations need to remain below Maximum Anticipated Operating Pressure
    - Hose movement causing kinks or pig blockage and potential pressure spikes
- Proper sizing of compressors to avoid over-pressuring the system
- Personnel/workers in the line of fire

IRP Operators and service providers should consider the following during winter operations:

- Pigging should be done during daytime for good visibility
- Storage volumes should be managed to ensure there is room during hot water flushing operations.
- Weather forecasts and temperatures to prevent freezing water transfer lines. Low ambient temperatures may require hot pills of water to be flushed through the line periodically to prevent freezing, therefore forecasting weather and fluid storage volumes is key to preventing freezing water transfer lines
- Ensure enough heating equipment is available to maintain good freeze prevention practices
- Flash freezing on metal components. When cold water is introduced to equipment that is well below freezing, then ice plugs can form in a very short period of time, leading to blockage in the line or equipment damage

- Freeze protection for long term shut downs, managing storage volumes, hot pills, re-circulation lines and purging
- High potential for ice slugs during pigging operations, causing damage to equipment or pressure spikes and potential for line of fire exposure

Appendix A: Revision Log

Edition 1

Edition 1 is the first edition of this new IRP sanctioned in 2024.

The following individuals helped develop Edition 1 of IRP 29 through a subcommittee of DACC.

Table 14. Edition 1 Development Committee

Name	Company	Organization Represented
Ernie Barker	TOPCO Oilsite	Enserva
Pam Blaney	Grimes Well Servicing Inc.	CAOEC
Adrian Campbell	ARC Resources	CAPP
Kevin Crumly	Trican Well Service Ltd.	Enserva
Matt Dagert	Treeline Well Servicing	CAOEC
Chad Dannish	Next Level Energy	CAPP
Jim Delsing	ConocoPhillips	CAPP
Glenn Doiron	Ideal Completion Services	Enserva
Rick Eckdahl	Chevron	CAPP
Kevin Elgert	Stream-Flo	Enserva
Corwin Gibbons	Isolation Equipment	Enserva
Kirk Grimes	Grimes Well	CAOEC
John Green	Ovintiv	CAPP
Daniel Harris	Canyon Rigging	Enserva
Kevin Holm	Precision Well Servicing	CAOEC
Nathan Kwasniewski	Stream-Flo	Enserva
Mike Nelson	Grant Production Testing Services Ltd.	Enserva
Greg Nichols	Trican	Enserva
Eric Plante	Calfrac Well Services Ltd.	Enserva
Andrew Robertson	AER	Regulator
Kris Sato	STEP Energy Services	Enserva
Trevor Schable	CNRL	CAPP
Craig Schroh	SMP Oil and Gas	Enserva
Bill Skea	Halliburton	Enserva

Name	Company	Organization Represented
James Sloman	Iron Horse Energy Services	Enserva
Doug Smith	Element Technical Services	Enserva
Dylan St. Germain	Safe-T-Whip	Enserva
Dave Thompson	Ovintiv	CAPP
Bob Toronchuk	STEP Energy Services	Enserva
Mike Uhryn	Safe-T-Whip	Enserva

Appendix B: Restraint Force Equation Theory and Examples

Restraint Force Equation Theory

To simplify the theory of how a restraint works, consider the physics behind a spring that is loaded by an applied force.

For a linear spring, one measures its stiffness or spring constant through Hooke's Law. Hooke's Law states that the force needed to extend a linear spring by some distance 'x' is proportional to that distance. Accordingly, the force equation for a spring is:

Equation 5. Force Applied to Spring

$$F_{spring} = kx$$

Where

F_{spring} = force applied to the spring (N)

k = spring constant (N/m)

x = axial distance the spring is displaced by the applied force (m)

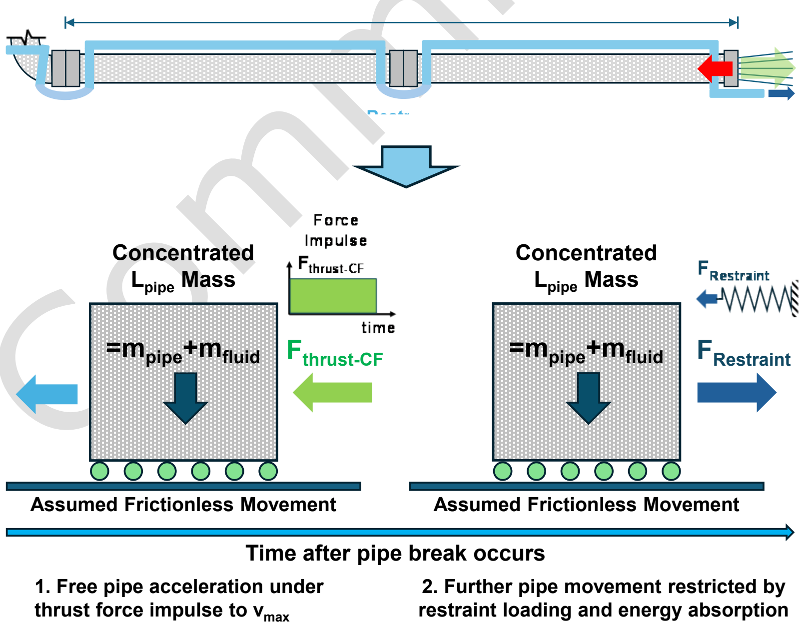
When a force is applied to a spring, the spring lengthens and absorbs the energy (i.e., stores it as potential energy). If the magnitude of the applied force is doubled, then the amount of spring displacement (stretch), will also double (i.e., and twice the amount of potential energy will be absorbed). If the elastic limit of the spring is exceeded by the applied force, then the spring will sustain permanent deformation and may break. Likewise, when a dynamic force is applied to a restraint because of a catastrophic failure of temporary piping, the restraint is expected to absorb the energy imparted to the pipe by the fluid jet in a spring-like manner.

As described in Sections 29.3.5 Understanding Dynamic Forces Related to Restraint Design and 29.6.1 Restraint System Design of this IRP, the fluid source conditions associated with a pipe break scenario (i.e., constant flow rate or constant pressure) need to be defined in order to establish the magnitude of the force exerted on the restraint. To understand the magnitude of the force exerted on the restraint in a constant flow rate (Pump Model) scenario, one needs to understand basic impulse and momentum principles (i.e., $F \cdot \Delta t = m \cdot \Delta v$) which define how the energy imparted to the pipe will be reacted by the restraint. This is explained further below.

As illustrated in Figure 50, when a pipe segment parts in a Pump Model scenario, a transient thrust force will immediately be exerted on that pipe segment. The unanchored pipe segment of length L_{pipe} and total mass equal to the combined mass of the pipe segment (m_{pipe}) and the fluid inside (m_{fluid}) will accelerate for as long as that thrust force is applied.

> **Note:** Force impulses of large magnitude and short duration (i.e., milliseconds) can be expected in this type of scenario. Under such rapid loading conditions, it is reasonable to assume that the unanchored pipe segment will start from rest and reach a peak velocity (v_{max}) as the force impulse ends which will occur before the restraint system engages. Once engaged, the restraint spanning across the pipe break section will begin to stretch and slow the movement of the pipe segment thus absorbing its kinetic energy ($KE= ½\ m_{total}\ v^2_{max}$). The maximum loading and stretch (displacement) of the restraint will occur when all the pipe kinetic energy has been converted to potential energy ($PE= ½\ k_{restraint}\ x$) and the pipe movement is fully arrested. In order to achieve this desired outcome, the restraint must have sufficient capacity to safely withstand this dynamic peak loading condition.

Figure 50. Thrust Force Impulse Loading of Unanchored Pipe Segment Followed by Restraint Engagement (Pump Model Scenario)



Note: For conservatism in restraint design and selection, in addition to frictionless fluid flow, it is assumed that the affected pipe segment remains intact, straight and aligned with the thrust force throughout the impulse duration as indicated in Figure 50, and that no energy imparted by the force impulse is dissipated through pipe segment friction, pipe bending, or other reactive load transfers.

The key factors which impact the amount of kinetic energy developed in the accelerated pipe segment which is subsequently transferred to the restraint itself include:

- The magnitude and duration of the fluid jet thrust force applied to the pipe segment
- The overall length of the unanchored straight pipe segment that aligns with the thrust force and its total mass including the mass of the fluid contained within it

In the case of a pipe break occurrence in a constant pressure source or Wellbore Model scenario, the fluid jet thrust force will have a different magnitude and, importantly, it can be expected to last much longer (i.e., potentially minutes to hours) than in a Pump Model scenario. Given the sustained duration of the thrust force applied to the parted pipe segment in this case, following an initial thrust force application and separation movement of the parted pipe ends required to engage the restraint extending across the break, the restraint will subsequently need to react to the full thrust force until the flow can be shut in. Accordingly, in this case the maximum restraint force is assumed to be equal to the sustained thrust force (i.e., $F_{thrust\text{-}CP} = 2 \cdot P_{AOF} \cdot A$) acting on the broken pipe. In compressible flow situations, the end user may wish to justify the use of a reduced thrust coefficient (see Section 29.6.1 Restraint System Design). As in the Pump Model scenario, for conservatism in restraint design and selection, this assumes that no energy imparted to the affected pipe segment by the continuous thrust force is dissipated through pipe segment friction, pipe bending, or other reactive load transfers.

Example #1 - Pumping Operations

Scenario Description

Hydraulic fracturing operations will be conducted on a pad with several wells. The temporary piping, from the outlet of the fracture pumps, will run along the ground with line segments connecting to each wellhead. The longest straight unanchored length of pumping iron between the fracture pumps and a wellhead is 35 m. The piping system consists of 76.2 mm, 103.4 MPa (3” 15ksi) pressure rated iron. The rated maximum allowable working pressure on the wellhead is also 103.4 MPa (15 ksi). However, the maximum pump pressure that can be applied to the piping system is limited by the rated burst capacity of the casing which is 86 MPa (12.4 ksi). Pressure testing on the temporary piping will be done to 10% above the burst on the casing (i.e., 95 MPa (13.8

ksi). Means such as pressure relief valves will be employed to ensure that the system pressure does not exceed this value.

> **Note:** Casing published burst capacity values are based on material yield strengths and therefore they reflect safety margins relative to actual pipe burst pressures. Therefore, if no other measure was employed to limit the pump pressure in the system, the actual pressure at the casing burst point would be higher.

The fracture program specifies the pumping of a slickwater design and 150 tonnes (165.3 tons) of sand per stage. The base fluid will be produced water with a friction reducer. The density of the produced water is 1,050 kg/m^3 (65.55 lb/ft^3).

The Production Engineer for the operator has determined that the absolute open flowing pressure this well is capable of is 25 MPa (3.63 ksi) through the parted temporary piping.

Discussion of Scenario

Since this operation involves a positive displacement pump connected to a wellbore via temporary piping, it is necessary to establish the maximum restraint force at a potential pipe break location by considering both fluid energy sources that may feed a fluid jet at that location – this includes both the pump system and the reservoir exposed to the well (see Figure 51 below). Accordingly, both constant flow rate and constant pressure scenarios as described above will need to be evaluated in this case. The end user will use the larger of the two forces established through the evaluations to select an appropriate restraint product for the piping system.

Figure 51. Example 1 Pumping Operations

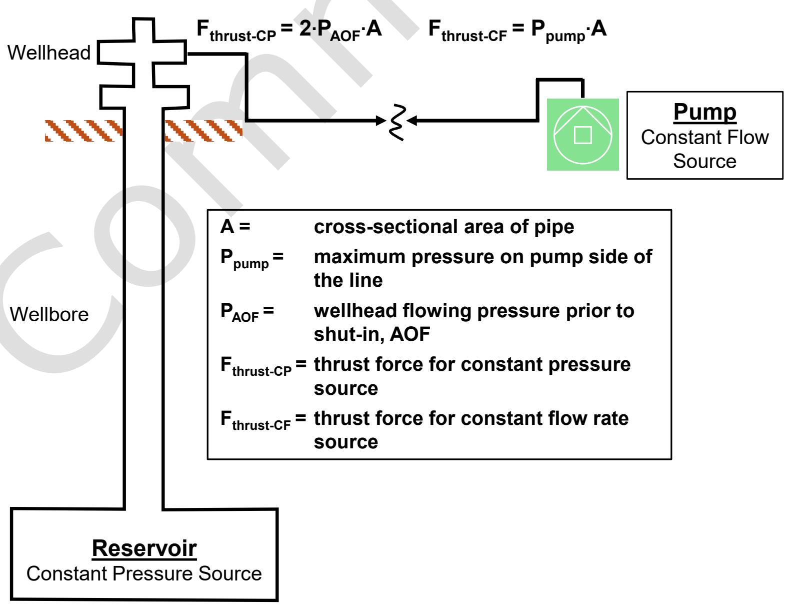


Table 15. Example 1 Assumed Parameter Values

Variable	Number	Units
Density of steel, ρ_{steel}	7,840	kg/m^3
Rated Working Pressure of Piping	103.4	MPa
Pipe OD	76.2	mm
Pipe ID	65.0	mm
Fluid density inside the pipe, ρ_{fluid}	1,050	kg/m^3
Speed of sound in fluid, α	1,481	m/s
L_{pipe}	35.0	m
Max pressure test	95.0	MPa
P_{AOF}	25.0	MPa

For the pump scenario, key parameters that can impact the calculated magnitude of the restraint system reactive force in the event of a pipe break include:

1. the longest straight length of unanchored pipe that is free to accelerate and move under the imposed thrust loading;
2. the maximum pressure the line will experience during the pumping operations;
3. the speed of sound in the fluid;
4. the pipe mass per unit length; and
5. the restraint stiffness.

The peak pressure values to be used in the calculations are established by the end user. This example will use a maximum pump pressure of 95 MPa which corresponds to a 10% increase above the theoretical burst capacity of the well casing. Alternatively, one could determine the peak forces on the restraint system based on the rated maximum allowable working pressure of the temporary piping.

The fracture fluid design can change from operator to operator, formation to formation, etc. While the speed of sound in the fluid will vary somewhat with fluid density, for both Consistency and simplicity while still employing a reasonable design basis, the freshwater speed sound of 1,481 m/s at 20°C will be assumed for the fluid system. For the fluid system density, this example will use the density of the produced fluid.

Note: The IRP allows for engineering judgement to be used in making assumptions related to the fluid parameters. For example, one could increase the density of the fluid if the density is confidently known. One could also change the speed of sound in the fluid used in the analyses if it is well defined at the expected operating conditions.

Example 1 Calculations

Constant Flow Rate Source (Pump Model):

For these calculations one assumes that the pipe system is fed by a constant displacement fracture pump when the break occurs. As a result, for the restraint design, the thrust force exerted on the parted pipe will be transient with a peak magnitude equal to the maximum pipe operating pressure multiplied by the internal cross-sectional area of the pipe.

The thrust force is calculated, as follows:

Equation 6. Thrust Force on Parted Pipe

$$A = \frac{\pi}{4} Pipe_{ID}^2$$

$$F_{thrust-CF} = P_{pump} A = P_{pump} \frac{\pi}{4} Pipe_{ID}^2$$

$$F_{thrust-CF} = (95{,}000{,}000\ Pa) \frac{\pi}{4} (0.0650\ m)^2$$

$$F_{thrust-CF} = 315{,}239\ N = 70{,}869\ lb_f$$

The next calculation is the time the thrust force is applied, Δt_{thrust}:

Equation 7. Time the Thrust Force is Applied

$$\Delta t_{thrust} = \frac{L_{pipe}}{a}$$

$$\Delta t_{thrust} = \frac{35m}{1{,}481 \frac{m}{s}}$$

$$\Delta t_{thrust} = 0.0236\ s$$

The total pipe/contained fluid mass (m_{pipe} + m_{fluid}) of the unanchored pipe segment can be calculated using the following formula:

Equation 8. Total Mass of Pipe and Fluid

$$m_{total} = \frac{\pi}{4} (Pipe_{OD}^2 - Pipe_{ID}^2) \rho_{steel} L_{pipe} + \frac{\pi}{4} Pipe_{ID}^2\ \rho_{fluid} L_{pipe}$$

$$m_{total} = \frac{\pi}{4} [(0.0762\ m)^2 - (0.0650\ m)^2] \left(7{,}840\ \frac{kg}{m^3}\right) (35\ m) + \frac{\pi}{4} (0.0650\ m)^2 \left(1{,}050\ \frac{kg}{m^3}\right) (35\ m)$$

$$m_{total} = 463\ kg$$

Assuming the restraint system manufacturer has a restraint that has a $k_{restraint}$ factor of 2,918,780 N/m based on the product pull test characteristics listed in Table 18, then the total force that would be applied to the restraint can be calculated as shown below in Equation 9 (i.e., due to the transient thrust force acting on the pipe segment).

Table 16. Example 1 Restraint Pull Test Results

Restraint Pull Test Results	Number	Units
Force Applied to Restraint	150,000	lbf
	667,233	N
Total Restraint Length Change	9.0	in
	0.23	m
$K_{restraint}$	2,918,780	N/m

Equation 9. Total Force on the Restraint

$$F_{restraint} = F_{thrust}\Delta t_{thrust}\sqrt{\frac{k_{restraint}}{m_{pipe}}}$$

$$F_{restraint} = (315{,}239\ N)(0.0236\ s)\sqrt{\frac{2{,}918{,}780\ \frac{N}{m}}{463\ kg}}$$

$$F_{restraint} = 591{,}494\ N = 132{,}973\ lb_f$$

Constant Pressure Source (Wellbore Model):

As described in Section 29.3.5, in the case of a hydraulic fracturing operation, the restraint installed across the break section may experience two sequential pipe thrust load applications. The first will occur from the pump side of the break which by nature will be a very short-lived transient or impulse load. The second load application will occur afterward when the well begins to flow back through the pipe on the opposing side of the break. This constitutes a constant pressure scenario and the thrust loading will persist until the well is shut-in. With the restraint loading formulation proposed for this scenario which equates the restraint load to the thrust force applied by the fluid jet to the pipe, it is an implied assumption that the pipe segment on the wellhead side of the break is free to displace sufficiently in the axial direction that the restraint will be engaged and will experience the full thrust load applied to the pipe.

Based on the example inputs described above, the maximum thrust force for the wellbore flow event can be calculated as follows:

Equation 10. Thrust Force on Restraint from Wellbore Flow Event

$$A = \frac{\pi}{4}Pipe_{ID}^2$$

$$F_{restraint} = F_{thrust} = 2P_{AOF}A = 2P_{AOF}\frac{\pi}{4}Pipe_{ID}^2$$

$$F_{restraint} = F_{thrust} = 2(25{,}000{,}000\ Pa)\frac{\pi}{4}(0.0650\ m)^2$$

$$F_{restraint} = F_{thrust} = 165{,}915\ N = 37{,}299\ lb_f$$

As indicated, in a continuous thrust loading scenario of this type, the maximum restraint force is equal to the fluid jet thrust force.

Example 1 Restraint Force Selection

The restraint forces calculated for the two distinct thrust loading events are summarized in the table below.

Table 17. Example 1 Summary of Calculated Restraint Forces

Energy Source	Thrust Force on the Pipe F_{thrust} (N/lbf)	Force on the Restraint $F_{restraint}$ (N/lbf)
Constant Flow Rate (Pump)	315,239 / 70,869	591,494 / 132,973
Constant Pressure	165,915 / 37,299	165,915 / 37,299

The peak force on the restraint would result from transient thrust force generated by the constant flow rate energy source, therefore the restraint should have a minimum capacity of 591,494 N (132,973 lb_f), plus an appropriate safety factor.

> **Note:** Based on the restraint stiffness value derived from the sample test, a restraint force of this magnitude would equate to a 0.203 m (0.66 ft) elongation of the restraint extending across the pipe break (this would need to be accommodated by commensurate pipe segment displacement).

Example 1 Results Discussion

From this example, it is evident that the thrust force exerted on the pipe is completely different from the force sustained by the restraint system in the constant flow scenario. The restraint system would see a peak force of 591,494 N (132,973 lb_f) whereas the peak transient thrust force acting on the pipe would be much less at 315,239 N (70,869 lb_f). Therefore, for this scenario, simply using the maximum pressure times the flow area (P*A) to calculate the peak force on the restraint system would result in use of a significantly under-designed restraint system for this application. Based on this assumption one might have selected a restraint product with a 448,822 N (100,000 lb_f) capability which would clearly be inadequate.

In contrast, using the constant pressure source thrust force equation with twice the rated pipe pressure times the flow area (2·P·A), as has historically been done in the industry, would lead to an overdesign estimate of the actual restraint requirements. Under this assumption, the peak force on the restraint would be 686,226 N (154,270 lb_f) which if used for restraint selection would lead to the unnecessary use of larger, more costly equipment.

In this example case, the restraint product sample was tested to a peak load of 667,233 N (150,000 lb_f) and under this load it stretched 0.23 m (9.0 in). This empirical load capacity can also be compared directly to the calculated peak $F_{restraint}$. On this basis, the load factor of safety, FoS, for this design becomes:

Equation 11. Factor of Safety

$$FoS = \frac{Pull\ Test_{max}}{F_{restraint}}$$

$$FoS = \frac{667{,}233\ N}{591{,}494N}$$

$$FoS = 1.13$$

The end user of the restraint system needs to decide whether this is an acceptable factor of safety given the dynamic loading conditions involved and the environment that the restraint system will be expected to operate in.

Example #2 – Flow Testing Operations

Scenario Description

Testing operations are to occur on a low pressured well where the shut in wellhead pressures will not exceed 8 MPa (1160 psi). An operator is flow testing the well to get it back on production after it experienced a hit from an offsetting hydraulic fracturing operation. The testing company has rigged up 50.8 mm 34.5 MPa (two-inch, 5,000 psi) temporary pipe for testing and a 9.93 MPa (1,440 psi) test vessel to flow the well and send the production fluids down the pipeline. The longest straight length of unanchored pipe laid between the wellhead and the tank manifold is 25 m (82 ft).

Discussion of Scenario

Since this is a well testing scenario and no pumps are involved in the operation, the forces on the restraint will result from two different constant pressure sources: the reservoir and the test vessel (see Figure 52). The restraint design needs to be evaluated based on the two constant pressure sources assuming the maximum operating pressures on either end of the break could be different.

Figure 52. Example 2 Flow Testing Operations

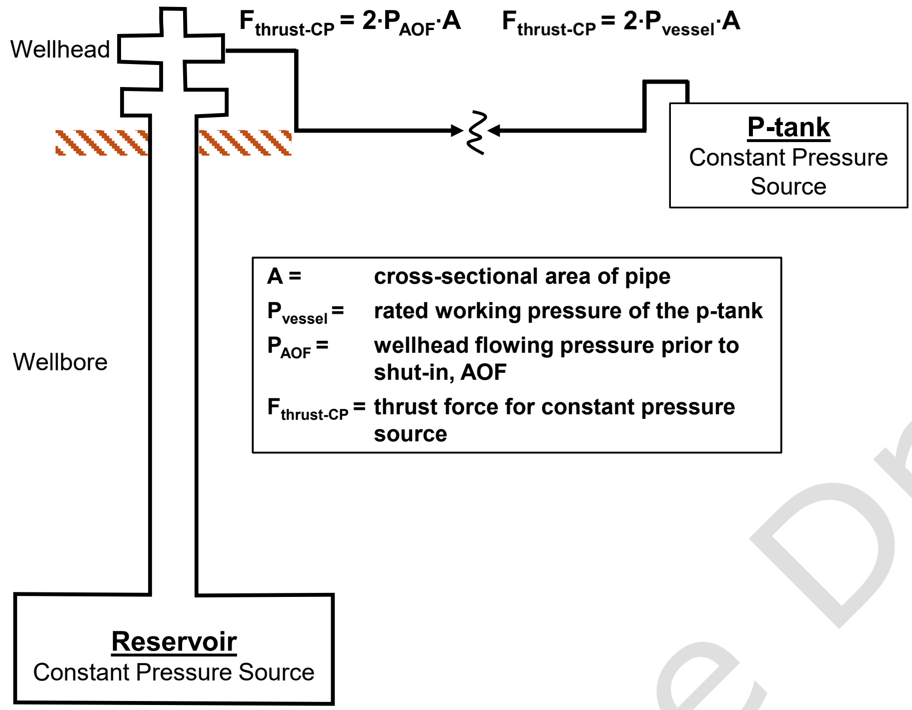


Table 18. Example 2 Assumed Parameter Values

Variable	Number	Units
Rated Working Pressure of Piping	34.5	MPa
Rated Working Pressure of Test Vessel	9.9	MPa
Pipe OD	50.8	mm
Pipe ID	40.0	mm
L_{pipe}	25	m
P_{AOF}	8	MPa

For this example, the analysis will consider the situation where the pipe is assumed to part while under the specified maximum shut-in wellhead pressure. However, in a real design evaluation, the assessment would need to include the maximum pressure the line will experience while in service. This would include the full pressure used to test the line, which is typically a minimum of 10% over the anticipated maximum operating conditions.

Example 2 Calculations

To determine the restraint force in this case, one needs to evaluate the thrust force exerted on the parted pipe by the fluid jet supplied from the constant pressure source (i.e., the reservoir). The estimated shut-in wellhead pressure will be used in this calculation. For this first part of the example, it is also assumed that the test vessel will not be exposed to pressures higher than the shut-in wellhead pressure of 8 MPa. Accordingly, the pressure rating of the test vessel can be ignored as a potentially higher source of energy in this initial restraint design analysis.

Having established this as a constant pressure scenario with the shut-in wellhead pressure of 8 MPa being the highest estimated pressure the line will observe from that source,the maximum thrust force on the piping system and the equivalent restraint force is calculated as follows:

Equation 12. Thrust Force on the Piping System

$$A = \frac{\pi}{4} Pipe_{ID}^2$$

$$F_{restraint} = F_{thrust} = 2P_{AOF}A = 2P_{AOF}\frac{\pi}{4} Pipe_{ID}^2$$

$$F_{restraint} = F_{thrust} = 2(8{,}000{,}000\ Pa)\frac{\pi}{4}(0.040\ m)^2$$

$$F_{restraint} = F_{thrust} = 20{,}106\ N = 4{,}520\ lb_f$$

Without an automatic tank shut-off system in place, a second, possibly coincident, loading event will take place from the pressure vessel side. Since it has been assumed that the maximum tank pressure is equal to the shut-in wellhead pressure of 8 MPa, both the pipe thrust force and the restraint force will be the same as determined above for the reservoir source case.

Note: Based on the approach adopted in the IRP for the thrust force formulations in the two scenarios, the impulse loading analyses is applied only to the situation where a pipe system is connected to a pump that generates fluid flow at a constant rate in the piping system while also serving to pressurize it. As described in Section 29.3.5, in such cases, the piping system will depressure from the break point back to the pump at the speed of sound in the fluid even though the pump may continue to operate and maintain the same rate of flow afterward. It is the temporary existence of a pressure differential along the pipe that gives rise to the transient thrust force which acts on the pipe. While this principle also applies for a pipe break in a Constant Pressure source case, without getting into all the details the key in this case is that the fluid jet and pressure differential will continue until the flow is shut-in and in the meantime, this will result in the thrust force acting on the pipe being fully reacted by the sling as described previously.

Example 2 Restraint Force Selection for Initial Assumptions

The restraint forces calculated for the two constant pressure loading events are equal as summarized in the table below.

Table 19. Example 2 Summary of Calculated Restraint Forces

Energy Source	F_{thrust} (N/lbf)	$F_{restraint}$ (N/lbf)
Constant Pressure Reservoir	20,106 / 4,520	20,860 / 4,690
Constant Pressure Vessel	20,106 / 4,520	20,106 / 4,520

Example 2 Results Discussion

In this situation, based on the assumptions made, the thrust forces from both constant pressure sources would produce the same peak sustained restraint force of 20,106 N (4,690 lb_f). Therefore a restraint rated for 44,482 N (10,000 lb_f) would be considered adequate, providing a load factor of safety of roughly 2.1.

Example 2 Alternative Design Assumptions

It may be feasible for an end user to consider another restraint design approach that will lead to the selection of a restraint design that will provide more consistency and flexibility in terms of covering a wider range of operating conditions with one configuration. While this alternative approach will inevitably result in the use of over-sized restraint systems in some applications, it avoids the requirement to size restraints for each individual operation with the same piping configuration. For this approach, the full pressure ratings of the pipe and/or other equipment and vessels connected to the system are used in the calculations as illustrated in this section of the example.

The temporary pipe was defined as having a pressure rating of 34.5 MPa while the test vessel pressure had a prescribed rating of 9.9 MPa. A constant pressure scenario applies in both cases once again for the thrust loading and restraint force calculations.

First, the thrust on the pipe is calculated as shown below for a maximum line pressure of 34.5 MPa. In this case it doesn't matter which side of the pipe break the pressure source is assumed to be on since the restraint force is considered equal to the pipe thrust force in constant pressure source situations.

Equation 13. Thrust Force on the Pipe

$$A = \frac{\pi}{4} Pipe_{ID}^2$$

$$F_{restraint} = F_{thrust} = 2P_{AOF}A = 2P_{AOF}\frac{\pi}{4} Pipe_{ID}^2$$

$$F_{restraint} = F_{thrust} = 2(34{,}500{,}000\ Pa)\frac{\pi}{4}(0.040\ m)^2$$

$$F_{restraint} = F_{thrust} = 86{,}708\ N = 19{,}493\ lb_f$$

Similarly, the constant thrust force and restraint load corresponding to constant pressure flow from the test vessel is established assuming the pressure vessel is operating at its 9.9 MPa maximum rating.

Equation 14. Thrust Force on the Restraint

$$A = \frac{\pi}{4} Pipe_{ID}^2$$

$$F_{restraint} = F_{thrust} = 2P_{vessel}A = 2P_{vessel}\frac{\pi}{4}Pipe_{ID}^2$$

$$F_{restraint} = F_{thrust} = 2(9{,}900{,}000\ Pa)\frac{\pi}{4}(0.040\ m)^2$$

$$F_{restraint} = F_{thrust} = 24{,}881\ N = 5{,}593\ lb_f$$

Example 2 Alternative Restraint Force Selection

The restraint forces calculated for the two conditions are summarized in the table below.

Table 20. Example 2 Alternative Approach Restraint Forces

Energy Source	F_{thrust} (N/lbf)	$F_{restraint}$ (N/lbf)
Constant Pressure Reservoir (to full pipe pressure rating)	86,708 / 19,492	86,960 / 20,224
Constant Pressure Test Vessel (to vessel rated operating pressure)	24,881 / 5,593	24,881 / 5,593

Example 2 Alternative Results Discussion

The results show that restraint selected for this application based on the initial operation-specific set of conditions would be under-designed in terms of meeting the increased capacity requirements established by using the specified pressure ratings of the equipment. In the case of the pipe rated pressure, the estimated maximum restraint force is 86,960N (20,224 lb_f) which is well above the 44,482 N (10,000 lb_f) capacity of the restraint considered adequate based on the first set of assumed limiting pressure conditions. The use of this alternate approach will generally lead to restraint designs that will require the use of higher capacity rated restraint systems to adequately resist the forces that could be developed under these limiting design conditions.

Conclusion

These two examples illustrate how restraints can be designs based on the assessment of various operating scenarios and use of different assumptions. One approach is to assess a piping and restraint system design specifically for an expected operating scenario with defined limits for pump and wellhead pressures as well as any pressure vessel ratings. However, if the operating conditions or equipment employed in the field change, then it becomes necessary for these calculations to be completed again with the revised set of inputs. The risk is the potential misapplication of a previously selected restraint system design should the assumed equipment layout or operating conditions change materially. Also, it may be quite cumbersome for some operators to continually update and track these calculations as well as ensure that whenever changes are required these outcomes are being properly implemented at the field level.

The second example introduced a simpler approach to restraint system design which instead uses the specified pressure ratings of the piping and equipment to determine restraint capacity requirements rather than using estimates of the maximum pressure conditions associated with a particular operation. While the use of this alternate approach will generally require the use of higher capacity-rated restraint systems (which will likely be over capacity for many operations), due to the inherent consistency it is quite possible that various organizational and cost efficiencies may be realized with the routine use of the higher rated restraint systems. They will also provide increased factors of safety in most cases.

Appendix C: Case Study

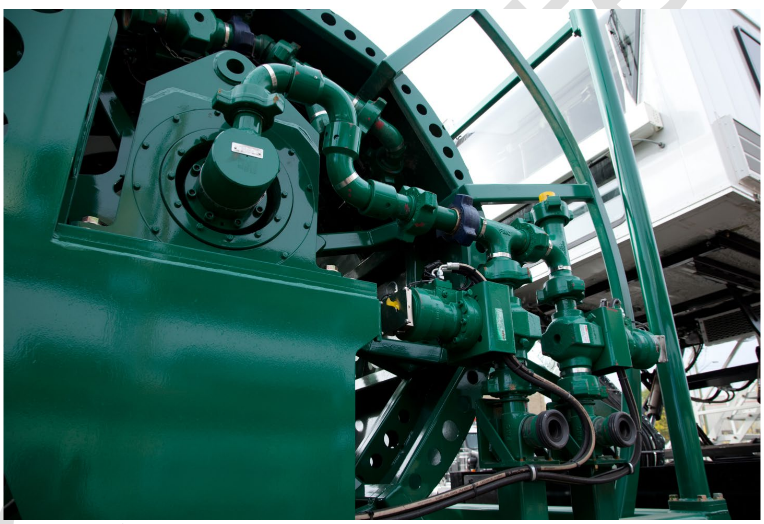
Introduction

An organization is evaluating the need for restraints within its coiled tubing operations. The internal treating iron assembled on the inside of coiled tubing reels is composed of several pieces which are connected from the CT string to the rotating joint. This piping typically consists of chicksans, plug valves, tees, and pup joints; these types of components are also used in the surface line pipework system from the pumping units. The internal coiled tubing reel manifold is supported in place through various brackets and mounts; these brackets and mounts are designed to support the weight and expected operational forces but are not engineered with the intent to handle the anticipated forces of a pipework failure. Therefore, the need for a pipework restraint system needed to be evaluated.

Figure 53. Coiled Tubing Unit

Figure 54. Coiled Tubing Reel Internal Manifold

Figure 55. Coiled Tubing Reel Internal Manifold



Risk Assessment

As part of the risk assessment for the determination of utilizing restraints on the coiled tubing reel internal manifold, several operational considerations specific to the organization's operational portfolio had to be assessed and evaluated to determine the entire risk.

- The organization's coiled tubing pumping rates are typically < 0.75 m^3/min and thus do not achieve the maximum erosion rates within the pipework system as set by OEMs.
- They typically do not pump abrasives within the pipework system.
- The pipework system is certified on a yearly basis.
- The organization typically maintains coiled tubing pressures to 65 Mpa; the pipework system is rated to 103.5 Mpa.
- The coiled tubing reel is within the organization's exclusion zone policy which minimizes the potential of personnel in its proximity during operations.
- The coiled tubing reel covers a large portion of the internal manifold acting as a partial cage.

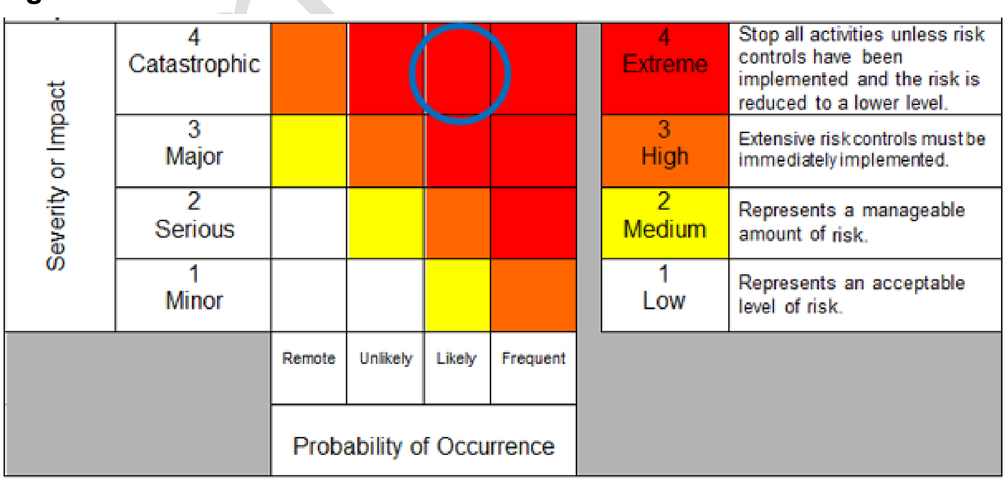
As the assessment was performed, a significant risk presented itself from the use of a synthetic sling type restraints within the coiled tubing reel. The coiled tubing reel is a rotating drum which feeds the CT string into the wellhead thru the use of an injector head. The potential for a restraint sling to get caught or bind on the inside of the CT reel as it rotates could have catastrophic impacts to the reel, CT string and the wellhead; including potential crane collapse, well control events, and/or loss of life.

With the considerations above, the organization made the decision **not** to restrain the coiled tubing reel internal manifold.

A comparison of the risk profile has been provided below:

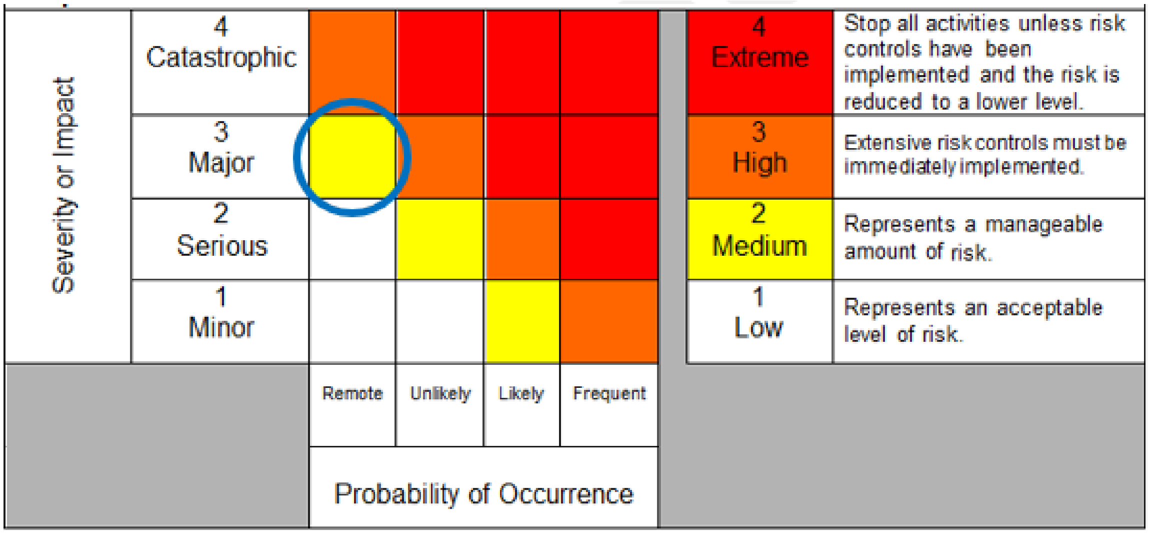
A) Scope: Utilizing Restraint inside CT reel on internal manifold
Potential Consequence: Nylon restraint gets caught or binds creating catastrophic surface equipment and wellhead damage.
B) Scope: NOT utilizing Restraint inside CT reel on internal manifold

Figure 56. Initial Risk Assessment



Potential Consequence: Internal manifold pipework system overpressures resulting in component separation and projectile.

Figure 57. Risk Assessment After Controls



The coiled tubing reel external manifold is being restrained with a synthetic sling as it is stationary and away from the rotating drum. The external manifold is not fastened with engineered mounts to act as a self-restraint.

Appendix D: Checklists

Pre-Rig In Inspection Checklist

Surface Location:				**Client:**		
Well UWI:				**Date (dd-mm-yy):**		
#	**Description**	**Checked**	**Corrected**	**Removed from Service**	**N/A**	**Comments**
1	Hard piping unions are in good condition, free of defects or damage and are not mismatched.					
2	Hard piping threads are in good condition, clean, and lubricated.					
3	Hard piping insert is present, properly installed and not warped or cracked.					
4	All three segments are present and the snap ring is in position.					
5	Flexible piping is free from cuts, abrasions, and other damage.					
6	The outer cover of flexible piping does not have signs of looseness, kinks, bulges, soft spots, abrasion, cuts or gouges.					
7	Restraint ‘in service’ date is current					
8	Restraints are appropriate to current or anticipated temperature conditions (e.g., cold weather ratings on shackles or synthetic fibres, temperature of pumped material)					
9	Tagged load rating of the restraint (tag) meets or exceeds rated maximum allowable working pressure rating of the piping system.					

10	Restraints are free from damage					
11	Hardware has all necessary and appropriately sized/rated components installed and are free from damage					
Verifier Name:			**Verifier Signature:**			
Date Completed:						

Installation Checklist

Surface Location:				**Client:**		
Well UWI:				**Date (dd-mm-yy):**		
#	**Description**	**Checked**	**Corrected**	**Removed from Service**	**N/A**	**Comments**
1	High pressure iron P&ID has been provided and approved by appropriate representatives (optional)					
2	Hard piping unions are in good condition, free of defects or damage and are not mismatched.					
3	Hard piping threads are in good condition, clean, and lubricated.					
4	Hard piping insert is present, properly installed and not warped or cracked.					
5	Hard piping has all segments secured in place and the insert condition and placement is correct.					
6	The outer cover of flexible piping shows no signs of looseness, kinks, bulges, soft spots, abrasion, cuts or gouges.					
7	Flexible pipe shows no signs of overbending.					
8	Flexible pipe end couplings show no signs of leakage, corrosion, erosion or cracking of the steel end.					
9	Flexible piping end couplings have inspection tags with records of inspection.					
10	Restraint ‘in service’ date is current					
11	Restraints are appropriate to current or anticipated temperature conditions (e.g., cold weather ratings on shackles or synthetic fibres, temperature of the pumped material					
12	Restraints are free from damage					

13	Hardware has all necessary and appropriately sized components installed and are free from damage					
14	Installation of the restraints does not interfere with operations					
15	Restraint system has adequate tension and no excessive slack					
16	Restraints are anchored appropriate to the application					
17	Installation of restraint system is as per manufacturer specification					
18	All company standard operating procedures, safety procedures and guidelines were followed during installation					
Verifier Name:			**Verifier Signature:**			
Date Completed:						

Appendix E: Glossary

See 29.2 Definitions and Regulations for additional definitions.

AER Alberta Energy Regulator

AMPP Association for Materials Protection and Performance

API American Petroleum Institute

ASME American Society of Mechanical Engineers

ASTM American Society for Testing and Materials (now ASTM International)

BCER British Columbia Energy Regulator

Burst Disk Pressure Relief Device utilizing a disk that ruptures to relieve pressure. Pressure tolerances on pressure relief for disks need to be provided by the manufacturer.

CAOEC Canadian Association of Oilwell Energy Contractors

CAPP Canadian Association of Petroleum Producers

Competent In relation to a worker, means adequately qualified, suitably trained and with sufficient experience, to safely perform the work without or with only a minimal degree of supervision.

Compressible fluid A fluid that experiences large changes in volume or density when pressure is applied during flow.

CSA Canadian Standard Association

CT Coil Tubing

CWP Cold Working Pressure

DACC Drilling and Completions Committee

Dynamic Load Any force that changes over time in terms of size, direction, and position.

Elastomer Any natural or synthetic rubber material capable of recovering its original shape after being stretched. Elastomers provide permanent or temporary seals in a variety of situations and equipment, especially well control equipment, used in drilling operations.

EPAC Explorers & Producers Association of Canada

ESD Emergency Shut Down (valve)

Exclusion Zone Is a designated area of hazards with the highest risk and requires authorization to enter.

Finite Element Analysis A computerized simulation based on a numerical method used to predict how a product reacts to real-world forces such as vibration, heat, fluid flow, and other physical effects.

Galling The tearing of metal when two elements rub against each other, usually caused by lack of lubrication or extreme contact pressure.

H_2S Hydrogen Sulphide

High Pressure Containing Components A component which is exposed to and contains pressure.

HPCC High Pressure Containing Components

Incompressible fluid A fluid, either liquid or gas, whose density remains constant during flow.

Iron Management System The purpose of iron management system is to ensure the integrity of the iron. They typically consider the potential for degradation of materials (e.g., erosion, corrosion, chemical/environmental degradation, temperature considerations, stress fatigue), pressure testing, material thickness testing, non-destructive testing, proper maintenance of materials and proper identification of tracking of information about the iron (e.g., in-service dates, inspections, manufacturer specifications). Refer to manufacturer recommendations for more detail.

IRP Industry Recommended Practice

Layflat Hose A flexible, lightweight hose that can lay flat when not in use and is used for the discharge and delivery of water.

LPT Line Pipe Thread

Maximum allowable working pressure The highest rated pressure that the system can withstand based on the maximum pressure of the lowest pressure rated component in the system.

Maximum anticipated operating pressure maximum pressure on the entire system during normal operations, static conditions, pigging operations and any other operating conditions the temporary pipework system is anticipated to be exposed to. MAOP shall not exceed MAWP.

MAOP Maximum Anticipated Operating Pressure

MAWP Maximum Allowable Working Pressure

MER Ministry of Energy and Resources

NACE National Association of Corrosion Engineers (NACE International)

> **Note:** NACE International merged with The Society for Protective Coatings to form the Association for Materials Protection and Performance (AMPP) in 2021.

NORM Naturally Occurring Radioactive Materials

NPT National Pipe Tapered

NPTF National Pipe Taper Fuel

NPS Non-Pressure Seal

NPST Non-Pressure Sealing Thread

OHS Occupational Health and Safety

Owner A trustee, receiver, mortgagee in possession, tenant, lessee or occupier of any lands or premises used or to be used as a place of employment and any person who acts for or on behalf of an owner as an agent or delegate. For the purposes of IRP 29, the owner is the person who possesses the worksite and/or product.

Pipework is the complete system of piping, restraints, and anchoring.

PPE Personal Protective Equipment

PPM Parts per Million

PRD Pressure Relief Device

Pressure Relief Device These are the primary pressure relief components. Devices include a pressure relief valve or a non-reclosing pressure relief device (burst disk).

Pressure Relief Valve are primary pressure relief valves that relieve excess pressure and reclose to prevent further flow after normal conditions have been restored.

Prime Contractor In relation to a multiple employer workplace, the directing contractor, employer or other person who enters into a written agreement with the owner of that workplace to be prime contractor or if there is no agreement, the owner of that workplace.

PRV Pressure Relief Valve

PS Pressure Seal

Relief Pressure Pressure that the PRD will open to de-pressure the system.

Restraint Safety system designed to control the release of stored energy if temporary pipework fails.

Restraint Owner The Restraint Owner could be the OEM restraint manufacturer, a service company that provide restraints for use with their temporary pipework, a third-party rental company or the prime contractor.

RWP Rated Working Pressure

SDS Safety Data Sheet

Securement Culmination of initial anchor point, restraint connections to individual temporary pipework sections and final anchor

Service Company Means a person, corporation or association who is contracted to supply, sell, offer, or expose for sale, lease, distribute or install a product or service to another company, usually the owner of the worksite.

Supplier a company that sells, rents, leases, erects, installs or provides equipment.

Swivel Joint (Chiksan) A series of short steel pipe sections that are joined by swivel couplings. The unit functions as a flexible flow line that provides a flow path between the control head and the floor manifold.

Temporary Pipework Temporary pipework, also called temporary flow piping, is the system of pipes used at wellsite for pumping into and out of wellbores (wellheads). It includes connections (e.g., hammer unions, flanged connections) and components like joints, valves, tees, and swivels that provide flexibility and adjust the system's orientation and elevation. Temporary pipework is used in services, but not limited to, swabbing, well flowback, cementing, well servicing, and well stimulation.

Thermoplastic Polyurethane A category of plastic formed by injection molding, blow molding, and extrusion that can be melted and reformed, resulting in a highly flexible, durable, light weight and abrasion-resistant elastomer.

Tolerance During testing, actual pressure release of a PRD should be within +/- 1400 kPa (200 psi) of the required relief pressure. For burst disks the criteria will be met through the review of the manufacturers tolerance documentation for the specific disk installed in the relief system.

UT Ultrasonic Testing

Water Transfer Water transfer is moving water with pumps using layflat hoses or other means, excluding tank trucks. Water transfer does not include tying to a wellhead, test package, or pressure vessel. Water transfer can occur on lease or off lease. See 29.11 Water Transfer Systems.

Working Pressure Maximum pressure on the pressure control equipment that must never be exceeded during field operations.

Appendix F: References and Resources

DACC References

Available from www.energysafetycanada.com

- IRP 04: Well Testing and Fluid Handling
- IRP 07: Competencies for Critical Roles in Drilling and Completions
- IRP 21: Coiled Tubing Operations

Local Jurisdictional Regulations and Information

Alberta

Available from www.alberta.ca:

- Occupational Health and Safety Code
- Safety Codes Act, July 2020

Available from www.aer.ca

- Directive 077: Pipelines – Requirements and Reference Tools
- Oil and Gas Conservation Act
- Oil and Gas Conservation Rules
- The Pipeline Rules
- The Pipeline Act
- Report 2009-A: Updates to Storage Requirements for the Upstream Petroleum Industry

British Columbia

Available from www.bclaws.gov.bc.ca:

- Energy Resources Activities Act
- Petroleum and Natural Gas Act

Available from www.bc-er.ca:

- Drilling & Production Regulation
- Oil and Gas Activity Operations Manual, Chapter 11 Pipeline Activity

Available from www.worksafebc.com

- Occupational Health and Safety Regulation, Part 23 Oil and Gas
- Workers Compensation Act

Manitoba

Available from www.gov.mb.ca:

- Drilling and Production Regulation, June 1994
- Workplace Safety and Health Regulations

Saskatchewan

Available from www.saskatchewan.ca:

- Directive PNG034 – Saskatchewan Pipelines Code
- Saskatchewan Ministry of Energy and Resources, The Oil and Gas Conservation Regulations
- Saskatchewan Occupational Health and Safety Regulations

Government of Canada Resources

Available from www.gc.ca:

- Canadian Oil and Gas Drilling and Production Regulations SOR/2009-315

Other References and Resources

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- ANSI/MSS SP-44-2019: Steel Pipeline Flanges. 2020. USA: Manufacturers Standardization Society of the Valve and Fittings Industry Inc.
- API 6A, Specification for Wellhead and Christmas Tree Equipment, twenty first edition. 2018. Washington, DC, USA: API.
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- API Recommended Practice 15WT, Operations for Layflat Hose in Oilfield Water Applications, first edition. 2019. Washington, DC, USA: API.
- API Recommended Practice 574, Inspection Practices for Piping System Component, fifth edition. 2024. Washington, DC, USA: API.
- API TR 6AF, Technical Report on Capabilities of API Flanges Under Combinations of Load, third edition. 2008. Washington, DC, USA: API.
- API TR 6AF1, Technical Report on Temperature Derating of API Flanges Under Combination of Loading. 1998. Washington, DC, USA: API.
- API TR 6AF2, Technical Report on Capabilities of API Flanges Under Combinations of Loading Phase II, fifth edition. 2013. Washington, DC, USA: API.
- API TR 6RT, Guidelines for Design and Manufacture of Surface Wellhead Running, Retrieving and Testing Tools, Clean-out Tools and Wear Bushings, first Edition. 2020. Washington, DC, USA: API.
- ASME B16, Standardization of Valves, Flanges, Fittings, and Gaskets. 2021. New York, NY, USA: ASME.
- ASME B16.5, Pipe Flanges and Flanged Fittings: NPS ½ through NPS 24, Metric/Inch Standard. 2020. New York, NY, USA: ASME.
- ASME B16.47, Large Diameter Steel Flanges: NPS 26 through NPS 60, Metric/Inch Standard. 2020. New York, NY, USA: ASME.
- ASME B31.3, Process Piping. 2022. New York, NY, USA: ASME.
- ASME PCC-2. Repair of Pressure Equipment and Piping. 2015. New York, NY, USA: ASME.
- ASTM A53/A53M-22, Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless. 2022. West Conshohocken, PA, USA: ASTM. https://doi.org/10.1520/A0053_A0053M-22.
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