



Best Management Practice

Use of High Density Polyethylene (HDPE) Lined Pipelines

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Overview

This guide is meant to provide increased awareness among designers, installers and users of high density polyethylene (HDPE) lined pipeline systems of some industry practices and lessons learned regarding HDPE lined pipelines, as used by the upstream oil and gas industry. This document is not intended to be a detailed guide, design manual or standard specification on the use of these materials for pipeline applications. Significant industry literature and documentation already exists on the design, manufacturing, installation, and operation of HDPE lined pipelines. This information currently resides in HDPE liner installation company literature.

In Canada, the oil and natural gas industry pipeline code standard, CSA Z662-2019¹, has a complete chapter dedicated to non-metallic pipeline systems (see Clause 13.0) that also includes specific requirements for HDPE lined pipelines (see Clause 13.2).

This guide is intended to complement these existing industry documents and standards, not to replicate their contents.

Therefore, the main intention of this guide is to address the following:

- Lessons learned and recommended best practices gathered from Canadian industry experiences; and
- Provide some guidance for designers, installers, and users who may have limited experience with HDPE lined pipelines.

In addition, pipeline operators should be aware of the applicable regulatory requirements for lined pipelines in the jurisdictions where they operate. This guide is not intended to describe or define the application of local, provincial, or municipal government regulatory requirements that may apply to lined pipeline projects.

Recommendation:

Users should consult with the manufacturers and installers of HDPE liners that are either in operation or being evaluated for use, for clarifications and their suggestions and advice regarding best practices, considerations and applications for liner installations.

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1 Project Scope

The scope of this document is to provide some best practices for users of fitted HDPE liners in oil and natural gas production industry pipelines.

1.1 HDPE Liners General

HDPE liners have been widely used for well over 30 years in Canada.

The term “liner” refers to a plastic lined steel system whereby the chemical resistance of an inner plastic liner pipe is combined with the strength of an outer steel carrier pipe. The liner is not bonded to the steel carrier pipe but is installed to be fitted in direct contact with the steel pipe wall. This configuration where the plastic liner is supported by the steel pipe allows the lined pipeline design pressure to be based on the strength of the steel carrier pipe. In other words, HDPE liners are internal corrosion barriers and not pressure-containing (e.g., HDPE liners are not free-standing fiberglass or reinforced composite products).

Liners are typically installed in the field into newly constructed pipelines or existing unlined pipelines that were previously in service.

Some more recently developed liner products now exist in Canada where the liner is factory-installed into individual pipe lengths and then field connected using proprietary special connections. This document does not specifically address these proprietary factory lined systems.

1.2 Service Application

The liner service applications discussed in this document are primarily intended for oil and natural gas field production or oilfield water pipeline systems as used by the oil and natural gas industry in western Canada.

Other specialized fitted liner applications may also be relevant and applicable, such as for plant process water transfer pipelines or pipelines in abrasive fluid services.

1.3 Pipe Size

Pipe sizes can vary from NPS 2” to NPS 52” or larger depending on the service application and installation method. Although it is technically possible, liner installation companies typically do not recommend lining NPS 2” pipelines.

2 Applications of HDPE Liners

2.1 General

HDPE liners are used by the oil and natural gas production industry for various pipeline services. Services include the following applications:

- Oil, natural gas, water multiphase fluid pipelines.
- Natural gas gathering production pipelines.
- Oilfield water injection or disposal pipelines.

In most cases, HDPE liners are initially considered and installed to provide longer-term operating benefits to the pipeline operator. Initial liner installation costs will vary given the prevailing market conditions and price fluctuations for both steel and HDPE and must be determined on a project basis.

Regardless of the initial material and installation costs, the potential for reduced operating cost is a primary consideration. Where possible, economic comparisons between lined and unlined carbon steel pipe should be based on total life cycle costs that consider the initial capital costs and the ongoing operating and maintenance costs.

Resistance to corrosive agents within the service fluid, such as wet carbon dioxide or dissolved salts, is one of the primary benefits of HDPE liners that can provide operating cost savings.

Unlined steel pipelines in corrosive services generally require various measures to control internal corrosion, such as the injection of a chemical corrosion inhibitor on a continuous or batch basis, internal thin film organic coatings, or the use of pigging to remove stagnant water accumulations. Such methods may require some additional operating costs including corrosion inspection and monitoring costs that will continue over the life of the pipeline. In some cases, these methods may not be totally effective in preventing corrosion.

For both lined and unlined steel pipelines, external corrosion control is provided through the provision of an external protective coating, cathodic protection (CP) installation, and regular CP monitoring/maintenance.

HDPE liners may provide increased resistance to the buildup of deposits such as paraffin waxes or scale on the pipe internal surface. These are benefits derived from the smoother pipe wall surface plus the lower thermal conductivity and higher specific heat capacity of HDPE material compared to steel pipe. Table 2-1 provides typical thermal properties of HDPE liner to compare with carbon steel pipe.

Table 2-1 Typical Thermal Properties for HDPE Liner versus Steel Pipe

| Material | Thermal Conductivity, W/mK | Specific Heat, J/kg K |
|------------|----------------------------|-----------------------|
| Steel Pipe | 50 | 450 |
| HDPE Pipe | 0.5 | 1900 |

Internal corrosion of bare carbon steel pipe can lead to the buildup of scales or fouling deposits. Such buildups may have a significant effect on pump pressure drop performance and lead to increased power consumption or decreased injection-well performance.

The internal surface of an HDPE liner is slightly smoother than new steel pipe, however, the surface finish of new steel can in some services degrade over time and become rougher due to corrosion and scale deposits.

Table 2-2 provides some of the typical published values of surface roughness and the Hazen Williams flow coefficient for HDPE pipes compared to carbon steel pipe. The typical values given in Table 2-2 are for general information only. For surface roughness values for individual pipe products, the pipe manufacturer's product specifications should be consulted, and their specified values used for individual project evaluations.

Note: In some cases, the benefit of the smoother liner surface may offset or partially offset the reduction in internal diameter of the lined system.

Table 2-2 Typical Values of Surface Roughness of HDPE and Steel Pipes

| Material | Surface Roughness, mm | Hazen Williams Flow Factors |
|-----------------------------------|-----------------------|-----------------------------|
| Steel Pipe, new | 0.040 | 130-140 |
| Steel Pipe, lightly rusted | 0.400 | 100 |
| Steel Pipe, very rusted or scaled | 3.400 | 60-80 |
| HDPE Pipe | 0.005 | 155 |

3 Liner Design

3.1 Service Conditions - General

Lined pipeline design requires a thorough understanding of the intended service conditions on a per-project basis that includes the expected normal operating conditions and possible operating upset conditions.

Throughout the design process, liner installation companies should be consulted to provide technical assistance and input based on their product installation requirements, past experiences, and proven capabilities.

Some key design parameters that must be considered in terms of initial and future forecasted operation are:

- Service fluid composition and any fluid changes expected over life.
- Operating pressure range including the amplitude and frequency of pressure cycles, start/stops, etc.
- Maximum operating temperature, temperature excursions.

Requirements for pipe risers, valves and branch connections. Operating conditions also include requirements for:

- Pigging for cleaning or internal inline inspections (ILI).
- Hot-oiling.
- Additive chemicals such as alcohols (e.g., methanol) or strong solvents or other treatments.
- Well downhole stimulation chemicals such as acids or solvents that could flow back into the lined pipeline.

Recommendation:

The range of operating service conditions, upset conditions and the effects of chemical additives should be understood and included in the design analysis. Discussion with the liner installer's technical staff can provide guidelines and is strongly recommended.

3.2 Design Pressure

The design pressure of HDPE lined pipelines is based on the steel pipe's capability alone. Since the steel pipe provides the mechanical strength, HDPE lined pipelines can be designed for very high-pressure pipeline systems such as water injection pipelines.

CSA Z662-19 does not apply any special pressure reduction design factors for lined pipelines.

However, a consideration is that lined pipelines are installed in separate segments that are re-connected, normally with flanged connections, therefore the flange pressure rating must be included when determining the maximum design pressure.

The designer must also be aware of scenarios where the potential pressure buildup in the liner interstitial annulus space, due to permeation of gases and hydrocarbon liquids, may be equal to the pipeline operating pressure. This is an important consideration for operation of HDPE lined pipelines to prevent liner collapse as discussed in Section 3.10.

3.3 Design Temperature

One of the most important aspects of liner design is to determine the maximum design temperature. Since HDPE is a thermoplastic material, its mechanical properties are significantly affected by the material temperature. Increasing temperature will lower the physical properties such as tensile strength and Young's modulus and render the liner more vulnerable to buckling collapse stresses and long-term material creep under sustained stress. Creep for liners however is limited since the liner is contained by the steel host pipe.

Figure 3-1 shows the effect of temperature on the yield strength of two typical HDPE liner materials. For this example, note the slightly improved strength of PE 4710 grade versus PE 3608 grade.

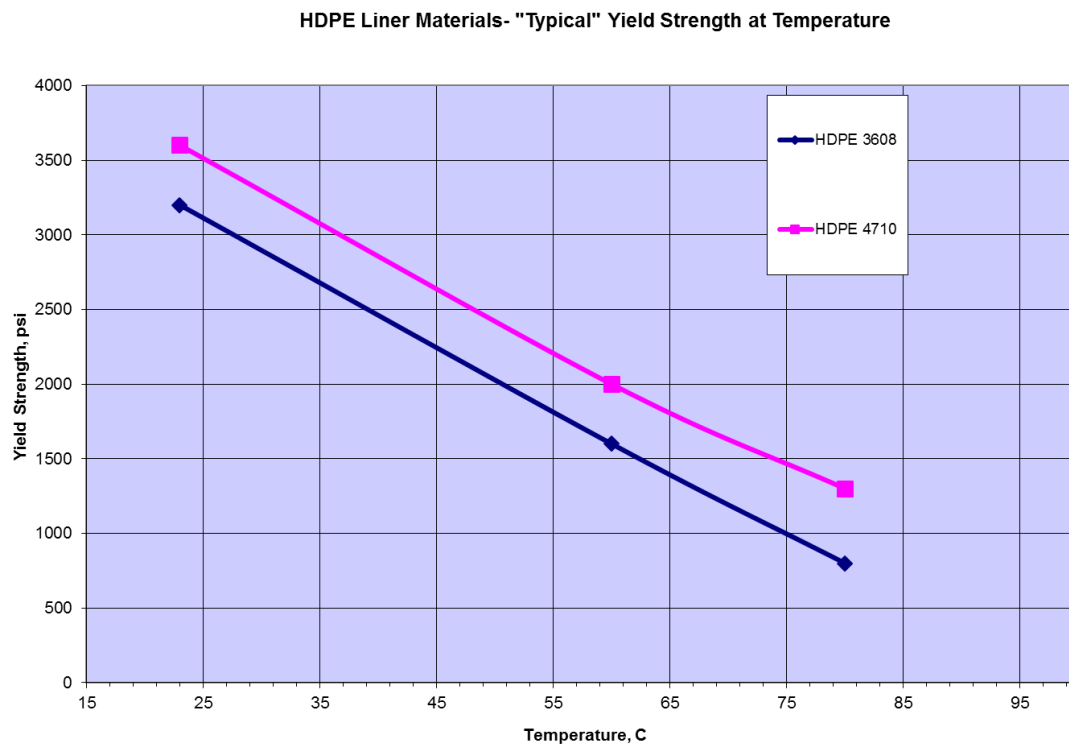


Figure 3-1 HDPE Liner Typical Tensile Yield Strength at Temperature

In general, as a free-standing pipeline material, standard HDPE is normally rated by industry standards to a maximum service temperature of 82°C depending on the grade. However, when installed as a liner, industry experience has shown that even higher service temperatures up to 95°C may be tolerated in some cases with specialty high temperature HDPE grades, but operators need to be aware that the likelihood of liner collapse and possible failure also increases, due to the loss of mechanical strength caused by elevated temperature operation.

Generally, experiences in water pipelines indicate the risk is lower for liner collapse when the liner remains full of an incompressible liquid. There are many examples where HDPE lined water systems operate successfully at temperatures up to 80°C and in some cases higher. However, caution must be exercised in operating at such high temperature as the liner material retains very little of its physical properties and becomes increasingly vulnerable to buckling or collapse.

For multiphase oil or raw natural gas gathering pipelines that operate at temperatures above 60°C, there is greater risk of liner failure due to collapse. In these services the gas and liquid phase constituents will permeate the liner and gas phase may condense in the annulus between the liner and steel pipe. The annulus gas phases remain compressed behind the liner while in service. In such cases the pipeline operating temperature may be restricted to 45-50°C to help reduce the possibility of liner buckling and collapse.

For multiphase services where liquid hydrocarbons are present, such as gas condensates or crude oil, physical absorption of the liquid hydrocarbons lowers the strength of HDPE liners. This effect on the liner's mechanical properties must be considered and is discussed further in Section 3.6.

Therefore, the maximum design temperature is based on the pipeline service fluid conditions and any upset conditions that may prevail. The designer should also take into account that future service fluid temperature may significantly increase over time due to changes such as increasing water cuts or the introduction of high-volume downhole pumps, such as electric submersible pumps (ESPs).

There are no hard-set limits published on upper design temperature for HDPE liners, but users must be aware of increased risk of liner buckling or collapse due to much diminished physical properties of HDPE liners that will occur due to elevated service temperatures. Follow the manufacturers recommendation for continuous service maximum temperature.

In industry there are various liner design models, used to estimate buckling differential initiation pressure. These models have been developed by end users and liner manufacturers to help with the liner design. These are discussed in Section 3.10.

Recommendation:

Based on industry experience general guidelines are as follows:

Wet Gas gathering – 60°C with some operators restricting gas lines to 45°C.

Multiphase mixtures - 60°C.

Water – Manufacturers recommendation for continuous service maximum operating temperature.

3.4 Differential Pressure

During operation in systems that contain gas phase the lined pipeline will experience a buildup of pressure in the interstitial annulus space between the inner liner and the steel carrier pipe. If not vented, the annulus pressure will gradually build up to the pipeline operating pressure due to gas permeation.

When the lined pipeline internal operating pressure is reduced there can be a differential pressure between the annulus and the liner. If the differential pressure exceeds the collapse pressure capability, the liner will buckle inward away from the steel pipe wall and may fully collapse in some cases.

The differential pressure causes gas to expand as governed by Boyle's Law and the volume of a gas is inversely proportional to the gas pressure, at a fixed temperature, see equation 1.

$$\text{Volume Gas} \propto 1/\text{Pressure} \quad (V_2 = P_1V_1/P_2) \quad (\text{Equation 1})$$

For example, in a natural gas system operating at 5000 kPa pressure with the same annulus pressure, the annulus gas expansion ratio is approximately 50:1 if the pipeline internally was fully de-pressured to atmospheric pressure (100 kPa) and maximum differential pressure conditions exist. As shown by Equation 1, the expansion ratio will vary up or down based on the initial pipeline operating pressure (V_1).

Also note that the volume of annulus gas is relatively small, however when the gas migrates to the lower pressure, downstream end of the pipeline liner section, it may accumulate into a larger volume and cause a liner collapse lobe. In some cases, a liner collapse lobe that occurs mid-section can transfer compressive stress to the end flanged connection and place the flange stub end adaptor fitting under deformation stresses and may cause failure of the butt fusion welded joint or the stub end body material. Installation of the liner stub end fitting requires quality fusion welding to help resist elevated stresses that can occur in service.

Therefore, the designer must be aware of the potential for liner collapse and consider options for the liner design that include the effect of service conditions on the physical state of the liner. Operators must also have operating procedures to manage annulus gas pressures and ensure that the maximum differential pressure capability of the liner is not exceeded.

Sections 3.5 and 3.10 provide some more information on gas permeation and estimating the liner collapse initiation differential pressure.

3.5 Permeation

All plastics will allow gases to permeate to some extent. The volumes of gas are generally very small, however, if not vented, the annulus pressure will eventually build up to the pipeline operating pressure.

The rate of permeation varies for different plastics. The gas type will also affect the rate of permeation. Carbon dioxide (CO_2) and hydrogen sulfide (H_2S) gases have relatively high rates of permeation while methane gas (CH_4) has a relatively low rate. For example, permeation constants published for CO_2 indicate three to four times higher permeation rate than for CH_4 . Therefore, different gas types present within the annulus due to permeation will initially exist at different concentrations than present within the pipeline service fluid. Over time, the gas composition in the annulus tends to be closer to the composition in the mainline. It should be noted that for sour gas systems, depending on how the annulus pressure is managed, the liner annulus can have a higher H_2S concentration than is present in the service fluid.

Other factors beyond the gas permeation constant that affect the rate and volume of gas permeation are:

- Liner surface area (diameter) and wall thickness affect the volume of permeated gas over a set time.
- Operating pressure differential across the liner affects rate.
- Operating temperature, as a higher temperature will accelerate permeation rate.

In terms of impact on liner design, if a gas phase is present in the service fluid then gas will likely permeate into the liner annulus over time. Permeation will occur at different rates based on the gas composition and liner variables mentioned above. The gases will continue to permeate until equilibrium pressure is reached between the operating pipeline and liner annulus.

Note also that other gases, including water vapour or volatile chemical vapours, such as from methanol additions, can also permeate through the liner. In some cases, vapours may condense in the annulus to form a liquid phase and can cause or accelerate issues with regard to corrosion of the steel carrier pipe. See Section 3.7 for further discussion.

3.6 Absorption (Swelling)

Physical absorption is a process where a substance in one physical state is transferred into another substance existing in a different physical state. An example is transfer of a liquid into a solid-state material.

In relation to HDPE pipeline liners, liquid hydrocarbons are absorbed into the solid liner material. The degree of absorption relates to a few factors but is primarily based on the type of liquid hydrocarbons.

HDPE is very resistant to water absorption and is considered a hydrophobic polymer material. However, HDPE readily absorbs hydrocarbon liquids such as crude oil, condensate and various solvents. Aromatic hydrocarbon solvents and cyclic solvents such as cyclopentane and cyclohexane are more highly absorbed than straight chain alkane solvents.

The effect of hydrocarbon solvent absorption is to plasticize the HDPE and lower its physical properties such as tensile strength and Young's modulus. In this sense absorption has a similar lowering effect to temperature on HDPE liner material properties.

Another effect of hydrocarbon absorption is to physically swell the HDPE liner and cause increased volume, typically around two to four per cent volume swell. In aromatic hydrocarbons, such as cyclopentane, benzene, toluene and xylene can experience volume swell by as much as 10 per cent.

In some cases, excess swelling of the contained liner may generate compressive stress buildup in the liner wall that leads or contributes to buckling or decreases the liners resistance to collapse.

Within manufacturer's temperature limitations, physical absorption of liquid hydrocarbons by HDPE does not chemically alter the HDPE liner material molecular structure, since no chemical reaction takes place and the effects are largely reversible upon removal from the liquid hydrocarbon exposure.

Absorption of hydrocarbons is a gradual process for HDPE liners and testing indicates approximately one month of exposure may be required to achieve saturation and maximum volume swelling. Likewise, the de-absorption process takes a similar time to occur.

3.7 Chemical Exposure

In oil and natural gas applications of pipeline liners consideration of the chemical resistance must be made. Generally, HDPE is a very chemically resistant material. In Section 3.6 above, fluid absorption is discussed and only the liner's physical properties are affected but this is not considered the same as "chemical attack" where the chemical reacts with the liner material and the liner's properties are permanently degraded.

Generally, typical oilfield production fluids would not be expected to chemically attack HDPE, but they can cause loss of physical properties by absorption as discussed previously. HDPE is also resistant to chemical attack by gases such as H₂S and CO₂. For liner design, the exposed reduced physical properties that consider both temperature and hydrocarbon exposure of the HDPE liner should be used.

One area of concern would be additive chemicals used for wellbore or pipeline cleaning or prevention of deposits. In all cases these chemicals should be verified as acceptable before use. Generally, if chemicals are added at low concentrations (e.g., <500 ppm) or added only occasionally as batches that flow through and exit the lined system quickly, the chemical effects should be minimal. In some cases where multiple chemicals are added, the synergistic effect on liner performance may be worse than for individual chemicals, therefore the potential effect of chemical combinations should also be considered. Liner suppliers can provide chemical resistance charts for consultation. Exothermic chemical reactions also must be considered that generate temperatures above the liner design temperature.

Greater caution is warranted where lined pipelines are shut in and allowed to soak for longer durations with high concentrations of chemicals. Methanol (MeOH) is a very common oilfield additive chemical that is used to prevent hydrates from forming and plugging gas gathering and multiphase pipelines. For lined pipelines methanol has also been injected into annulus vents to clear plugging of vent and vent piping. MeOH is capable of vaporizing in the gas phase or mixing with hydrocarbon liquids and water and being absorbed by HDPE liners and transported into the liner annulus.

Note: In some cases, presence of methanol (MeOH) in significant amounts has been linked to annulus corrosion where H₂S gas was also present. ^{6,7,8,9}

Recommendation

In general during the design process, lined pipeline operators should review the service fluid including use of chemical additives with the liner supplier and if any doubt exists regarding chemical compatibility, laboratory exposure testing may be required. Methanol additions for hydrate prevention or for clearing of annulus vents for lined pipelines should evaluate risk of increased annulus corrosion as reported in industry.

3.8 Liner Material Selection

Most of the industry experience with pipeline liners has been with HDPE. There has been some limited use of other polymers such as polyamide 11 (PA 11) polyamide 12 (PA 12) and cross-linked polyethylene (PEX), and there is interest in other polymers such as polyvinylidene fluoride (PVDF), but no significant use of these liner materials has occurred in industry to date, due to several factors especially the increased cost of these alternative materials.

In addition, other factors must be considered such as chemical resistance and sensitivity to oilfield additive chemicals as discussed in section 3.7. For example, the properties of PA 11 are negatively affected by methanol and high temperature water exposures causing hydrolysis. However, polyamide polymers are resistant to hydrocarbon solvents.

Installation procedures, fusion procedures, etc., must also be developed and field-proven with alternate liner materials. In general, alternate thermoplastic liner materials would likely be installed using similar techniques and equipment used for HDPE.

For HDPE, the liner designer generally does not have a lot of material selections. Two grades of HDPE have been historically used for liners, PE 3608 and PE 4710. For many years PE 3608, previously known as PE 3408, was the workhorse of the liner industry but currently PE 4710, with slightly improved physical properties and environmental stress crack resistance, has evolved over the past 15 years into the HDPE liner material most used.

CSA Z662-19 specifies in Clause 13.2, that a minimum cell classification of 345464C be used, based on ASTM D3350. This minimum cell classification covers both PE 3608 and PE4710 materials.

Grade PE 4710 material would have physical properties that exceed the minimum cell class specified by CSA Z662-19. A typical ASTM D3350 cell classification for PE 4710 is 445474C.

A comparison of some key properties for PE 3608 and PE 4710 is as follows:

- Higher environmental stress cracking resistance (ESCR) for PE 4710.
- PE 4710 has a base resin density between 0.947 to 0.955 g/cc that increases with 2% carbon black addition to 0.956 to 0.964 g/cc.
- PE 3608 has a base resin density between 0.940 to 0.947 g/cc that increases with 2% carbon black addition to 0.949 to 0.956 g/cc.

A key difference between PE 3608 and PE 4710 is the increased ESCR resistance with PE 4710 having a longer duration 500-hour PENT test requirement versus 100 hours for PE 3608. In terms of liner applications, this property matters more at higher operating temperatures, where HDPE is known to be more susceptible to ESCR failure.

PE 4710 also provides slightly increased physical properties, such as tensile strength as shown in Figure 3-1 and Young's modulus that are both advantageous to pipeline liners.

It is understood that liner installation companies are currently using primarily PE 4710 liner materials; however, the designer should verify the proposed liner properties and the material grade with the liner material supplier.

3.9 Liner Wall Thickness

Often the liner wall thickness selection is determined and proposed by the liner supplier in consultation with the pipeline owner. It is based on the supplier's expertise, installation technique, experience, and prediction of liner collapse resistance. However, it is recommended that the pipeline owner or their representative take an active role and participate in the design of HDPE liners and not leave this solely to the liner supplier.

A primary consideration in selecting the liner wall thickness is to provide a stable liner that will be more collapse resistant under the service conditions of the pipeline.

Collapse resistance is directly related to liner wall thickness, diameter, and tightness of fit and several other service-related factors that are discussed more in Section 3.10.

3.10 Liner Collapse

Liner collapse mainly affects liners in gas or multiphase pipelines, although industry experience has shown that liners can also collapse in liquid-only services such as water – but the driving mechanism and cause may differ.

In some cases, where produced water pipelines are fed directly from a multiphase separator, some hydrocarbon liquid and gas carryover may occur in the water phase and can affect the liner properties over time, depending on amounts and frequency/duration of exposures.

Liners installed in gas or multiphase pipelines are typically more susceptible to collapse due to buildup of permeated annulus gas pressure that expands when the liner internal pressure is reduced below a critical differential collapse initiation pressure, P_c .

In other services such as oilfield water injection pipelines, liner collapse may occur due to vacuum operating condition.

As discussed in Section 3.4, liners may buckle under the differential pressure of the annulus in relation to the internal pressure of the liner. Once the initial liner deformation occurs it may proceed to fully collapse since less additional force is required to extend the collapse length after initiation.

Liner collapse may not occur due to a single event cycle and may occur over several events to initiate and develop a fully collapsed liner. Collapse resistant liners have a critical buckling pressure that is higher than the maximum annulus pressure.

Collapse resistance is somewhat affected by the tightness of the liner fit in the steel carrier pipe, with more tightly fitted liners having increased critical collapse resistance due to residual pressure of the compressed liner as it tries to expand back to its original diameter against the smaller ID host pipe. The residual pressure of the compressed liner increases the amount of differential pressure required to initiate a collapse lobe. ²

Various buckling equations exist for estimating collapse initiation pressures of encased pipes, and technical papers explaining principles and industry practices have been published.^{3, 4, 5}

Liner installation suppliers may also have a preferred collapse estimation model and therefore should be consulted for doing any liner collapse modelling estimations.

HDPE liners are typically installed in two categories of fit:

Expanded (loose) fit - a liner that during installation has an outer diameter smaller than the inner diameter steel carrier pipe. While in service, if the operating pressure is sufficiently high, the liner is expanded radially and is tight against the steel carrier pipe. If the service fluid contains liquid hydrocarbons such as crude oil the liner can also swell due to absorption and expand. When the service pressure is reduced below expansion

pressure the liner may retract, but this may take some considerable time to occur. Therefore, if pressure fluctuations are of short duration the liner may remain tight and the collapse resistance would not be significantly affected or different than a tight fitted liner. However, if the liner retracts and becomes loose, the outer steel pipe typically provides little restraint to the liner during collapse and thereby has reduced collapse resistance compared to a liner that remains tightly fitted against the steel pipe.

Oversized/Neutral fit - a liner outer diameter is equal (neutral) to or larger (tight) than the nominal steel pipe inside diameter. The liner diameter is rolled or swaged down mechanically during the liner installation. The outer steel pipe provides partial restraint to the liner to help resist buckling stresses. The liner remains more tightly fitted against the steel pipe regardless of internal pressure.

Loose Fit Liners:

An equation for estimating collapse initiation pressure for a retracted or loose-fitting liner is given by:

$$P_c = 2.5 E / (1-\nu^2) (t/R)^3 * 100 \quad \text{(Equation 2)}$$

where:

P_c = Critical collapse initiation pressure, kPa

E = Liner Young's modulus, MPa¹

t = Liner wall thickness, mm

ν = Liner Poisson ratio

R = average radius of liner, $R = (R_o + R_i) / 2$

where;

R_o = Outer radius, mm

R_i = inner radius, mm

Tight Fit Liners:

An equation for approximating collapse initiation pressure for a tight-fitting liner without swelling is given by:

$$P_c = 2.334 E (t/R)^2 * 100 \quad (\text{Equation 3})$$

where:

P_c = Critical collapse initiation pressure, kPa

E = Liner Young's modulus, MPa¹

t = wall thickness, mm

R = average radius of liner, mm, $R = (R_o + R_i) / 2$

where;

R_o = Outer radius, mm

R_i = inner radius, mm

If hydrocarbon liquids are present in the service fluid that result in liner swelling, then Equation 3 is modified as follows:

$$P_c = E (t/R)^2 (2.334 - 0.0385 \epsilon_{\text{swell}} R/t) * 100 \quad (\text{Equation 4})$$

where:

P_c = Critical collapse initiation pressure, kPa

E = Liner Young's modulus, MPa¹

t = wall thickness, mm

ϵ_{swell} = liner swell (%)²

R = average radius of liner, $R = (R_o + R_i) / 2$

where;

R_o = Outer radius, mm

R_i = inner radius, mm

Notes:

1. The Young's modulus (E) used in Equations 2, 3 and 4 should be representative of the HDPE liner material at the design temperature and include allowance for any possible reductions or increases due to chemical absorption or de-absorption.
2. Liner swell is defined as the average swell across the liner thickness.

Table 3-1 below, if a typical HDPE liner material's published Young's modulus was 700 MPa at 23°C the value recommended for use at 60°C may be 60 per cent lower at

approximately 250 MPa. If exposed to crude oil at 60° C the modulus value may need to be further decreased, based on the recommendations of the liner supplier.

Table 3-1 “Typical” Material Properties of HDPE *

| Temperature | 23°C | 40°C | 60°C |
|----------------------------|------|------|------|
| Modulus, air or water, MPa | 700 | 450 | 250 |
| Modulus, crude oil, MPa | 525 | 340 | 190 |
| Swelling, crude oil, % | 2 | 3 | 4 |
| Poisson Ratio | 0.35 | 0.38 | 0.40 |

*The properties shown are typical only for information and actual liner properties and degree of swelling may vary based on HDPE material grade. Therefore, the properties must be determined on a case basis for the proposed liner material and verified with the liner supplier or based on testing results.

Vacuum Collapse:

Where pipelines may be exposed to vacuum events during operation or shutdowns, this must also be considered for design of liners. Vacuum more often occurs in liquid filled pipelines such as water injection systems, when the pipeline stops flowing during a plant shut down and the pipeline is drawn down due to elevation differences over the pipeline topography or where water injection wells create a vacuum on the pipeline due to hydrostatic head.

For lined pipelines that may experience vacuum, the installation of a back-pressure control valve (BPCV) is recommended. The proper setting and ongoing maintenance of the BPCV are critical to prevent liner collapse.

Liners that operate at elevated temperature are more susceptible to vacuum collapse due to the significant decrease in the physical properties of the liner, as discussed previously.

Recommendation:

The liner modulus value to be used for collapse pressure estimation should be obtained from the liner supplier for the HDPE material grade proposed and be adjusted for both the pipeline maximum operating temperature and if applicable, exposure to hydrocarbons. Hydrocarbon types will vary in terms of their swelling effect on HDPE based on constituents such as aromatics and cyclic chain hydrocarbons. Liners that may undergo vacuum conditions due to elevation changes or operation should have back pressure control valves installed.

3.11 Grooved Liners

Although not commonly installed in Canada, in some cases the liner installer can supply a liner with several manufactured external grooves positioned axially on the liner outside surface.

The intention is to provide an improved pathway for the more efficient movement and venting of fluids from the annulus. Typically, grooved liners have been installed in gas pipelines, for situations where liner collapse is identified as an increased risk. They are normally installed on heavier wall thickness liners to account for the depth of the groove.

Grooved liners may provide increased venting efficiency for long liner segments or where annulus vents are interconnected to provide venting at fewer selected locations. This may be advantageous for long length sour service liners where a scrubber system can be utilized for removing H₂S from vent gas.

Safetyliner™ is an example of an available HDPE liner product utilizing external grooves.

The longitudinal orientated grooves are installed during the HDPE liner pipe extrusion at the manufacturing plant. The grooves are typically in the range of 2.5 mm depth and 5.0 mm wide with rounded bottom to reduce stress concentration effects, but the groove dimensions can vary based on the liner supplier's recommendations. See Figure 5-2 for an example of a grooved liner.

Groove depth and shape must also be reviewed and controlled for liner installations to ensure the plant and field installed grooves in relation to the liner wall thickness do not affect the liner integrity.

3.12 Lining Existing Pipelines

The installation of a liner within an existing pipeline that has been in service is relatively common. Reasons can include a change of service to more corrosive fluid or internal corrosion concerns. In terms of liner design, the process is very similar to design of liners for newly constructed pipelines.

The lining of a steel pipeline as a method to repair any leaks in the steel carrier pipe is not permitted by CSA Z662-19. Any leaks must be repaired or removed, and replacement sections of pipe installed before installing a liner.

CSA Z662-19 specifies an integrity evaluation of the steel pipe prior to liner installation as follows:

A four- hour leak test with water at the pipeline design pressure.

A four-hour leak test at a lower pressure than the current design pressure, in which case the design pressure is lowered to the four-hour test pressure.

An engineering assessment to determine the integrity of the steel pipeline based on operating history, intended design pressure, inspection results, and assessment of known defects.

Prior to lining an existing pipeline, steel fittings such as elbows or tees that may be installed in the pipeline must be located and removed. The weld quality of the steel pipe, regarding excessive internal penetration of the weld bead or the presence of severe defects such as grapes, icicles, etc., at circumferential welds, which could potentially damage the HDPE liner, must be evaluated and removed.

This is normally accomplished by running sizing pigs with steel sizing plates that can locate and, in some cases, remove these damaging weld area defects. If the pig is run on a wireline cable equipped with an odometer, it will accurately determine where the sizing pig is unable to pass.

Another concern is the presence of any dents or kinks in the steel pipe that must be removed prior to installing the liner. These can also be located using sizing plate pig runs.

After the sizing pigs are run, pulling a short section of liner pipe through the steel pipeline is recommended. This step allows a visual inspection of the short section of liner at the exit location and helps to determine the presence and effect on the liner of damaging anomalies.

3.13 Pipeline Risers

Two approaches are normally taken regarding risers for HDPE lined pipelines:

- Do not line the riser with HDPE. In these cases, the riser is transitioned below ground to an unlined riser with flanges, typically with an internal protection system, use of a corrosion resistant alloy; or
- Insert a liner within the steel riser connected to an above-ground flange.

With the first approach some operators may choose to internally plastic coat the riser piping to prevent internal corrosion. Usually for this case the riser piping is constructed using elbow fittings. For external corrosion use of a protective coating and cathodic protection are installed.

For the second approach where the riser is HDPE lined, the riser must be constructed using long radius pipe bends, to allow the liner to be pulled through. The minimum acceptable bend radius must be determined and verified with the liner installation company. Typically, longer radius bends such as 30D to 50D have been employed but in some cases lower radius bends have been installed if required due to space limitations. The second approach provides for easier maintenance pigging and for future running of inline inspection tools through the lined pipeline. ^{10, 11, 12}

The riser bends may be lined in conjunction with a short straight length of the pipeline that extends away from the base of the riser, determined in consultation with the liner installation company. Note that the shortened length of the liner section at bends does however need to be sufficiently long to enable the liner to be stretched out at the flange for installation of the flange stub end adaptor.

The installer needs to allow adequate relaxation time for the liner inside bends to ensure proper expansion of the liner to the steel pipe wall.

Recommendation:

Caution must be exercised when pulling the liner wireline cable through the bend as cutting of the bend wall (intrados) by the sliding steel cable may occur. Generally, when lining bends, the liner should be inserted through the bend end of the pipeline segment to minimize duration of cable sliding contact through the bend.

The use of special pull-in ropes or cables to minimize damage to riser bend sections is also used in some cases.

The ability to line pipeline bends at risers must be discussed with the liner installer and is based on bend radius, pipe diameter, riser wall thickness, liner installation method and length of the liner segment involved at the riser.

If the riser section and above-ground piping are constructed of heavier wall thickness pipe, usually this can also be lined based on increased liner roll down and installation of a shortened liner section. Therefore, this aspect of lined riser design requires discussion with the liner installation company.

Riser and interconnected piping including valves should be compatible internal diameter to allow for future pigging including running of internal in-line inspection tools (ILI) or be prepared to install temporary spools to allow ILI surveys.

The steel risers receive cathodic protection as part of the steel host pipeline systems that remains cathodically protected following the liner installation.

All metallic risers and metallic below-ground components that are connected to lined pipelines should receive internal and external corrosion control in accordance with CSA Z662-2019 Clause 9.

Where either solid corrosion-resistant alloys (CRA) or corrosion-resistant metallic coatings are used in lined pipeline systems, additional external corrosion protection (e.g., polymer coating, cathodic protection) may not be required, provided that a technical assessment by the Owner company indicates adequate corrosion resistance for the intended life of the pipeline. The technical assessment should include consideration of the following:

- a) expected life of the alloy or metallic coating;
- b) potential for external corrosion at coating holidays; and
- c) effect on the life of the coating because of such holidays.

3.14 Pipeline Bends

Minimum bend radius for the pipeline at field bends and for shop bends installed at riser locations is reviewed and determined for lined pipeline projects by the liner installer and project designer. Usually longer radii bends are used, such as 30D or 50D, as determined based on the liner diameter, length of liner pulls and installation method.

4 Construction Design

4.1 Vent Locations

Vents are required to remove annulus pressure buildup due to the permeation of gas and to check for liner breaches. CSA Z662-19 requires operators to monitor vents regularly.

Annulus vent stations are normally placed at the opposite ends of lined pipeline segments adjacent to the flanges. The vent locations must be selected and installed prior to inserting the liner. Consult with the liner installer to help select liner vent stations.

The location of vent stations must be carefully selected based on the following:

- Requirements for liner installation pull-in points, maximum liner pull-in forces, maximum length of liner sections.

- Access for installation equipment, liner assembly and stringing on surface, liner insertion and connection bell holes, etc.
- Proximity of water crossings, high water table conditions and drainage.
- Proximity of public facilities, roads, trails, etc.
- Long-term access by operating personnel for monitoring vents.
- Frequency of venting requiring access to the vent location.
- Adequate spacing to facilitate proper venting of accumulated gases.

In some cases, shorter liner pull section lengths, below 500 meters, have been installed by some operators for higher permeation rate gas services, such as CO₂. Liner vents are constructed of weldolet fittings typically 12.5 mm (½") nominal size, tubing, and a valve. The vent hole size is normally 3.2 mm (1/8") diameter but in some cases is larger diameter to reduce risk of vent hole plugging with scale or debris. The vents are installed on the pipe at the 12 o'clock position, typically within 375 mm (14.75") of the flanges. Figure 4-1 shows a schematic drawing of a typical liner flange connection.

In some cases, the installation of two vents at 12 and 2 o'clock positions have been used to reduce the risk of vent efficiency loss due to plugging.

To help prevent the liner sealing off the vent under pressure, usually for high pressure gas gathering pipeline applications, a stainless-steel screen mesh is applied to the liner just below the vent hole to provide separation of the liner and vent hole. Figure 4-2 shows a liner flange stub end assembly fitted with a screen.

Often the vents are installed below ground level with riser tubing that is fixed to an above-ground post. In some cases, access culverts are installed to provide permanent access to the liner flanges and vent piping.

Installation of vent jumper tubing to interconnect the annuli of lined segments is sometimes done. This is to move the vent monitoring stations away from obstacles such as difficult to access sites. Caution should be exercised as risks of losing the ability to isolate and identify location of liner breaches or spilling produced fluids over into the annuli of all jumpered sections could occur when vents and annuli are interconnected.

Special precautions and procedures should be developed for venting procedures when dealing with lined sour pipelines. Caution is advised in that the concentration of H₂S in the liner annulus gas may be higher than the concentration within the mainline.

In some cases, operators have utilized portable or permanently installed scrubber systems to remove H₂S from the annulus vent gas.

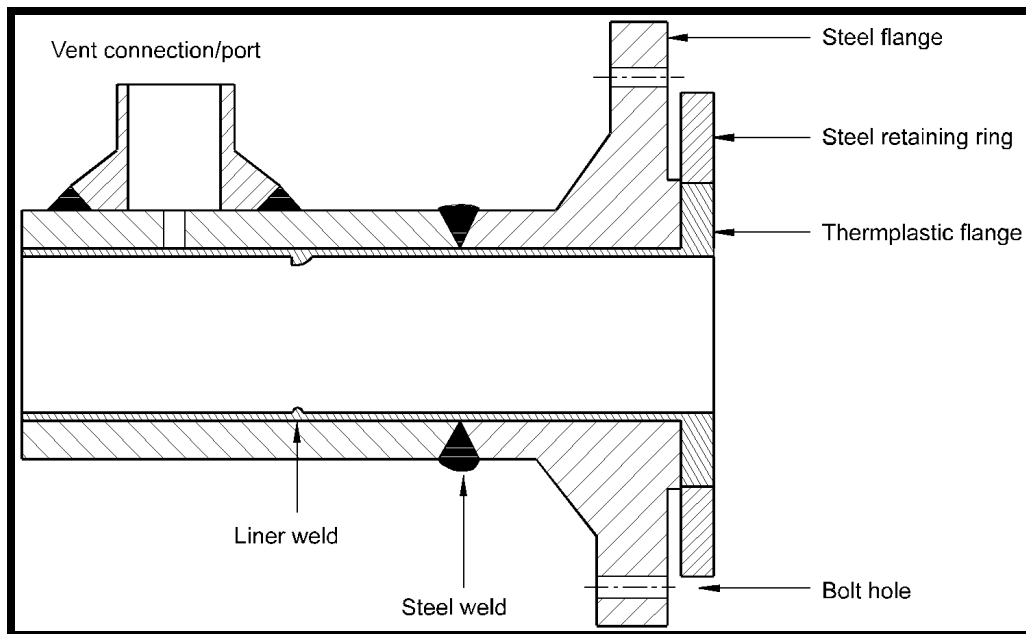


Figure 4-1 Typical Flange End Schematic



Figure 4-2 Liner Flange Adaptor and Vent Screen. Photo credit: John Baron

5 Liner Installation

5.1 General Installation Techniques

There are several commercially available liner installation methods employed by industry. Most available methods have proven to be effective methods for liner installation with certain advantages and disadvantages associated with each method.

The installation step is performed by specialized liner installation contractors in conjunction with the pipeline owner representatives, usually a pipeline construction or maintenance contractor company.

Therefore, pipeline liner installation projects should be planned and undertaken with consultation between the pipeline owner, the liner installer, and other companies. The other companies may be responsible for the pipeline construction and preparation for lining, installing vent stations, providing manpower assistance and equipment such as backhoes, tracked dozers or welding.

An overview of the generic methods most used for the installation of HDPE liners in oil and natural gas pipelines in Western Canada are provided below.

There are two generic liner installation techniques most used:

- Undersized loosely fitted liner, pressure expanded after insertion.
- Neutral or oversized tightly fitted liner, temporary liner diameter reduction and pull-in, after insertion the liner physically expands tightly against steel, as liner tries to revert to original diameter after pull-in.

Note: other methods of liner installation exist and are used internationally, such as liner folding or liner deformation to allow insertion, but these methods have not been commonly employed in Western Canada for oil industry pipelines although they may become more available in the future.

5.1.1 Undersized Liner Insertion (Expanded Fit)

Undersized liner installation involves inserting a liner of nominal outside diameter less than the inside diameter of the host pipe. Typically, the liner outside diameter will be in the range of 94 to 97 per cent of the steel carrier pipe inside diameter. The difference in diameter is the insertion clearance. It is the simplest technique for lining pipes and has a long history of use in oilfield pipeline applications.

Expanded fit is a technique where the undersized liner is simply pulled into the host steel pipe. The liner is slowly expanded radially in place by internal pressure, with or without heating, to yield the liner elastically in the hoop orientation, while the annulus is left open and vented. The application of heat is usually by use of heated water and is applied to help reduce the liner stiffness and ease the yielding of the liner.

An annular interstitial gap may remain. Internal pressure, creep and swell of the liner material are relied upon to obtain a tight liner fit after a period of operation. This time period depends strongly on the insertion clearance, liner material properties and the service pressure/temperature.

If the lined pipeline is not pressurized during shutdowns for extended periods, the liner may retract to its original undersized dimensions and become loose fitted. HDPE has a memory effect and may retain the expanded dimensions for considerable time and may not revert significantly and loosen if depressured.

5.1.2 Neutral or Oversized Tightly Fit Liner

Temporary liner diameter reduction with a set of profiled rollers is used to forge a reduced liner diameter in several reduction stages. In some cases, the last set of rollers in the roller box assembly may be powered, which helps to insert the liner into the host pipeline. Where the rollers are not powered the liner is simply pulled through the roller box by the wireline installation cable.

Temporary liner diameter reduction by passing the HDPE liner pipe through a sizing die is also used by some installers.

By controlling both the pull-in and diameter reduction loads, the conversion of liner length and resultant wall thickness is achieved while the diameter is reduced. Once installed inside the steel pipe, the liner will slowly expand radially out to the pipe due to its memory effect. Typical temporary liner diameter reduction may be in the range of 3 to 5 per cent of the original liner outside diameter, depending on the liner design and the installation equipment.

5.2 Pre-Installation Preparations

Preparation of the inside surface of the carbon steel pipeline will be influenced by whether the liner is to be installed in a newly constructed pipeline, or in an existing pipeline.

As described previously, awareness of the condition of the host pipeline is critical to ensure a successful lining operation.

To line existing pipelines, the preparation should include a review of the following:

- Corrosion damage, location, and extent.
- Presence of any leaks.
- Type and extent of internal deposits, cleanliness.
- Pipe diameter variations, pipe wall thickness.
- Locating kinks or dents.

- Weld quality regarding presence of penetrations, weld bead surface condition, presence of icicles, grapes or other protrusions and misalignment.
- Radius of field bends and shop manufactured bends, and fittings locations.

Prior to lining existing pipelines, the following actions are performed:

- Assessment of the steel pipeline to determine that sufficient mechanical strength is retained to meet the design pressure rating for the proposed service. This is based on an engineering assessment of operating results, inspection results or pressure testing (see Section 3.12).
- Repair or removal of unacceptable corrosion damage and fittings, bends, kinks, dents, wall thickness differences and other unacceptable weld restrictions.
- Evaluation of the internal condition and dimensions at welds and pipe to verify that the liner can be pulled through each segment without damage. Dimensions should be checked by pigs with sizing plates and by pulling a test sample of liner through.

Prior to lining either new or existing pipelines, the following steps are required:

- Determine locations for cutting and flanging of the line in consultation with the liner installation company. In general, the longest continuous length of liner which can be installed in straight pipe depends on liner diameter and wall thickness. The length of segments may be reduced by the presence of pipe bends. Breaks (flange locations) may also be required at road or water crossings.
- Determine the radius of field bends and shop manufactured bends, and fittings locations.
- Flanges welded to the steel line should be of matching bore and with a minimum radius at the inside edge of about 6 mm. Raised face (RF) flanges are normally specified but should be confirmed with the installer.
- Flange face separation distance, based on installers procedure, to allow space for liner stub end flanges and metal retainer ring installation between the flanges.
- In some cases the liner installer has requirements for trimming the outer circumference edge of the flange raised face, to provide a better fit of a steel retaining ring placed around the HDPE flange circumference.
- Vent weldolet fittings are welded to the line and the vent holes drilled in accordance with the project vent design (see Section 4.0).
- Overall project site conditions, personnel and equipment access, liner storage areas, locations for stringing out and assembly of liner on surface.

- Steel pipe and flange material selection. Special material requirements for sour gas service per CSA Z662-19, section 13.2.
- Steel pipe welding specification including limit on height of internal weld bead penetration and restrictions on presence of internal icicles, grapes or other defects that could cause liner damage.
- Pressure testing of steel pipeline before lining where required.
- Batching a corrosion inhibitor chemical through the steel host pipeline to mitigate corrosion behind the liner, performed immediately prior to the liner installation. This is not a regulatory mandatory requirement and not always performed for HDPE liners but is utilized by some operators and may be more of a consideration for lining of existing pipelines.
- Pigging of the steel host pipeline to clean deposits and for removal of any residual liquids and including pressure testing water. Thorough pigging or other methods of dehydration of the steel host pipe should be performed to ensure liquids are not trapped and remaining present in the liner annulus after the liner expansion. Residual water in the liner annulus interstitial space could contribute to future internal corrosion of the host pipe or plugging of annulus vents due to formation of ice, hydrates, or corrosion product scales. In some cases, dehydration equipment has been used to dry steel host pipelines to a very low dew point temperature internally immediately before lining.
- Where the assembled liner is pressure washed during installation to remove mud or other debris it should be thoroughly dried before insertion into the steel host pipe.
- Final pressure testing of lined pipeline as specified by CSA Z662-19, section 13.2 and local regulatory requirements

Installation of bell hole excavations that are in accordance with the liner installer's requirements and safety requirements. Considerations for bell holes include the following aspects:

- The working area within the bell hole should be of sufficient size to accommodate the liner installation equipment, roller box, fusion welding machines, operators, etc.
- The entry slope should enable the liner pipe to bend smoothly from ground level to the pipeline depth without severe abrasion against the steel flange during pull-through.
- Provision of sufficient length and width to enable the pipe ends to be offset for flange welding and pulling in the liner.

5.3 Liner Unloading and Storage

Unloading and storage of the liner pipes and reels should be done on site in accordance with the liner installer's recommended procedure. Care is required to ensure the liner is not crushed or flattened, creating significant ovality.

Normal HDPE liner materials contain approximately 3% carbon black loading that provides extended ultraviolet sunlight protection. For longer term storage durations, as specified by the liner installer, the effects of ultraviolet exposure must be considered and measures such as indoor storage or tarpaulins may be required to protect liner from damaging weathering effects.

5.3.1 Liner On-Site Inspection

Liner material should be visually inspected once offloaded on site, to look for possible shipping damage such as cuts from metal banding used on pipe bundles or chains or excessive ovality. Another opportunity to inspect the liner is during installation after it is cleaned and elevated off the ground. Another inspection opportunity is following the liner pull-in, at the exit flange location where a portion of the exited liner can be examined for gouges or cuts.

Surface defects identified during on-site inspection of the liner material should be marked and evaluated for cutout. Any defects exceeding the allowable inspection limits should be rejected and removed.

CSA Z662-19 specifies that liner damage during insertion of the liner, such as gouges and cuts, shall not exceed either the liner supplier's recommendations or be deeper than 10 per cent of the liner nominal wall thickness.

5.3.2 Repair of Defects

Defects in any form should not be repaired. Defects should be removed by cutting out the damage as a cylinder. Where the liner is found with defects exceeding the acceptance criteria it should be removed and discarded.

Where the liner is found to exceed the inspection limits at the exit point following insertion, the liner segment should be pulled out and the cause investigated, and remedial actions taken.

5.4 Vent Stations

Vent stations should be installed in accordance with the design and prior to the installation of the liner (see Section 4.1).

Every lined pipeline and flowline should incorporate vent points. Normally two vents per liner section are installed near to each liner flange location.

Vent holes should be designed such that no extrusion of the liner occurs through the vent hole. In some cases, multiple vent holes or wire mesh screens are used to improve venting, as discussed previously.

All vents should have shut-off valves and be equipped with suitable attached tubing/piping to allow routine venting and liner integrity monitoring checks by operations personnel. In some cases vents are interconnected (jumped), see Section 4.1.

In most cases below ground buried vents are installed and are externally wrapped with a suitable protective moldable petrolatum tape coating for external corrosion protection. The vent tubing is run to surface and mounted to a post or other marker. Livestock guards are often installed around vent stations.

In some cases, permanent bell hole culverts are installed as shown in Figure 5-1 to provide access to liner flange and vent connections.



Figure 5-1 Liner Vent Station Access Culvert (Liner Flange Connection Wrapped with Petrolatum Tape). Photo credit: John Baron

5.5 Liner Assembly/Fabrication

5.5.1 General

The thermoplastic liner pipe is joined using a butt fusion welding process, as specified in CSA Z662-19 (Clause 13.2.5).

Where alternative to HDPE liner and flange fitting materials are being installed, they may be joined using a fusion joining procedure that is provided and approved by the liner manufacturer, in consultation with the owner company.

Liner installation personnel performing the butt fusion welding must be trained and determined competent by the liner installer organization, this is also as specified by CSA Z662-19 (Section 13.2.5). The fusion procedure for the liner project is qualified based on tensile strength tests and bend tests of sample fusions. The tensile strength requirement for fusion welds is specified to be within 90 per cent of the liner pipe material tensile strength.

After completion of liner production fusion welding, the external bead of the weld is trimmed. Some owners also specify that the internal weld bead also be trimmed, which may be more important if maintenance pigging, internal crawler or inline inspection tools will be used. After bead trimming, the surface of the joint may be visually examined for evidence of good fusion. Any nicks, gouges or undercuts caused by bead trimming are generally not acceptable and should be removed by cutting out the weld.

For externally grooved HDPE liners, the grooves must be aligned for fusion welding, and after welding the excess melted HDPE material at the groove is removed as shown in Figure 5-2.



Figure 5-2 Grooved Liner Fusion Weld Excess Bead Trimmed (Safetyliner™)

5.5.2 Butt Fusion Joining Procedure

The liner installation contractor normally prepares a detailed heat fusion joining procedure for each type and size of joint and fitting to be welded. The procedure is based on the fusion parameters of the liner manufacturing company.

Ambient weather conditions such as low temperatures, rain or wind can negatively affect fusion welding. Therefore, it is highly recommended that fusion joining be performed in a weather-resistant area such as an enclosed trailer with heating. In addition, the fusion joining procedure may need to be modified for prevailing ambient conditions. Figures 5-3 and 5-4 show a typical liner fusion work site with liner stockpile, fusion welding trailer and fusion welding machine setup inside trailer.

HDPE liner material that has been in service may not be suitable for butt fusion welding due to presence of contaminants such as crude oil residue. To determine the suitability for welding, a test weld should be created with the liner material and the test weld evaluated for a porous or foamy appearance due to gasification of hydrocarbon contaminants during fusion welding and low bend strength. Either condition indicates that the material may be contaminated and cannot be butt fusion welded with confidence.

Where liners have been exposed to oilfield water primarily, fusion welding may be possible since oil contamination is less likely but may still exist in some cases due to trace oil content. Therefore the butt fusion welding procedure should be evaluated as mentioned above if trace level contamination is suspected.

The HDPE liner fusion joining procedure as a minimum includes (CSA Z662-2019 Clause 13.3.5.7)

- a) Equipment and tooling required.
- b) Joining surfaces preparation requirements.
- c) Heating tool temperature required for fusion.
- d) Heating soak times for each size and wall thickness of pipe.
- e) Alignment procedures and acceptable limits.
- f) Joining interfacial pressure and hold time requirements.
- g) Clamped cooling time requirements.
- h) Cooling handling time requirements.
- i) Elapsed time required before the joint can be subjected to high stress.
- j) Procedural modifications and precautions for cold weather joining methods.
- k) Precautions for inclement weather such as wind or rain.
- l) Documentation and traceability of fusions and fusion joiners' unique identification marking procedure.
- m) Visual assessment acceptance criteria.
- n) Production fusion joint destructive test method.



Figure 5-3 Typical Liner Assembly Worksite, Photo credit: John Baron



Figure 5-4 Typical Working Fusion Welding Machine in Trailer. Photo credit: John Baron

5.5.3 Fusion Testing

It is recommended that the fusion joining procedure and fusion technicians be qualified by the liner installer prior to liner assembly by the completion and testing of test joints.

The verification tests are performed using the project fusion equipment, project fusion operators and project liner pipe. The procedure qualification tests should be in accordance with CSA Z662-19 Clause 13.3.5.7.

A detailed fusion procedure and inspection test plan (ITP) should be developed for the fusion welding as specified by CSA Z662-19, Clause 13.3.7.1.

5.6 Liner Installation Steps - Typical

5.6.1 General

All equipment and material required for the installation and testing of the liner is normally provided by the liner installer. Other equipment is usually required such as backhoes or tracked dozers and is supplied by pipeline owner. In some cases, additional workers may be provided to assist and work with the liner installer.

Procedures to cover the installation of the thermoplastic liner inside the carbon steel pipeline are prepared by the liner installer and accepted by the owner.

5.6.2 Preparation

5.6.2.1 Pre-installation communications

The installer utilizes radio communication between the ends of the liner pull section prior to the start of the liner pull-in.

5.6.2.2 Pipe cleaning

Before installation, the installer runs various pigs to clean the pipeline and then demonstrates that the bore of the carbon steel pipeline is free from obstructions (e.g. excessive weld penetration, dents, fittings, etc.) that could interfere with or damage the liner during pull-in. That is typically accomplished by pulling through the steel unlined pipeline a pig train with a metallic sizing plate and wire brushes.

In some cases, the pipeline may be batch-pigged and batched with a corrosion inhibitor chemical where specified by the owner and the chemical is confirmed as compatible by the liner supplier. See Section 5.2 for further discussion regarding pipeline preparation measures prior to insertion of the liner.

5.6.3 Wireline Unit

The liner installer's wireline unit should be equipped with an odometer and load cell that requires regular calibration. The odometer and load cell should be equipped with a chart recorder to provide a permanent record of the liner pull-in loads. Overload control should also be set to prevent exceeding the allowed pulling force. The wireline reel should have a speed controller to allow variable rates to be employed and have an effective braking mechanism.

5.6.4 Wireline Pig Runs

The liner installer should provide suitable pigs and launching equipment to propel the wireline and pig train through the pipeline.

A typical pig train should include:

- Cup pig.
- Sizing plate pig.
- Wire brush pig.
- Short test section of liner pipe if undersized or rolled down

Once the wireline has been passed through the pipeline section, the pig train is pulled through, the pulling force being continuously monitored to determine the location of any tight spots.

For insertion of undersized liner pipe, the sizing plate diameter should generally be about midway between the outer diameter (OD) of the liner and the inner diameter (ID) of the steel pipe.

For insertion of reduced diameter, rolled down liner pipe, the sizing plate should be of sufficient diameter to verify that internal weld beads do not protrude excessively, considering the dimensional tolerances of the steel pipe.

Normally the details of the sizing plate dimensions are left to the liner installer to determine in consultation with the owner.

The OD of the liner pipe test segment should be such that any excess weld penetration which could result in liner puncture during normal operation is detected. For loose liners this could imply that a larger diameter liner pipe may be necessary for test purposes than during operation.

The liner test segment attached to the pig train should emerge without significant damage evident. Minor scuffing or light scratching of the liner surface is generally permissible but sharp longitudinal scars, gouging or damage exceeding either the liner supplier's recommendation or 10 per cent of the wall thickness are unacceptable and would require additional pigging using a breaker pig before continuing with the liner installation. To verify, another liner test segment should be pulled through.

5.7 Liner Insertion

5.7.1 General

Liner insertion techniques depend on the method of installation, as described in Section 5.1.

Note: As mentioned previously most liners are installed in the field but some new liner products may be factory-installed and employ special proprietary connections for field installation.

Installation methods and procedures should be provided by the liner installer and include as a minimum:

- Description of equipment used.
- Length of sections.
- Maximum allowable and planned axial pull load. The maximum allowable axial stress in the liner should be limited to 50 per cent of the liner materials tensile yield stress.
- Type of lubrication – lubricant if specified by the liner installer, is typically water but other lubricants have been used and should be specified by the installer and approved as compatible with HDPE liners. A caution when using lubricants is that some lubricants may accumulate and possibly interfere with annulus venting, therefore their selection and use should be considered in consultation with the liner installer.
- Liner pull-in rate.

- Methods for continuous load monitoring with calibrated equipment.
- Precautions shall be taken to ensure that no debris or wash water is introduced into the line on the external or internal surface of the liner. Liner pressure washing and drying prior to insertion has been employed to clean liner surface of mud. For grooved liners pressure washing is usually required as the grooves will trap mud during assembly and movement across ground soil surface during pull in.

5.7.2 Wireline Pull-in load

The actual pull-in wireline load should be continuously monitored during pull-in and should not be allowed to exceed the maximum allowable pull-in load (Section 5.6.3).

5.8 End Flanges and In-Line Flanged Joints

Connections between thermoplastic lined pipes and metallic piping such as risers are normally bolted flanges as described previously. In recent years proprietary or specialty welded or non-welded mechanical connections have been developed by some liner installation companies as an alternate to flanged connections but their use by industry has been limited to date.

The design of the thermoplastic lined flanges is proposed by the liner installer and agreed with the owner company. The design of the lined flanges should be raised face with spacer/retainer rings (see Section 4).

When the liner has been pulled in, HDPE flange adaptors are fusion welded to each end. The method should be detailed by the liner installer but generally involves the following:

- Welding the flange adapter fitting to the liner segment trailing end and then pulling the liner end tight against the steel flange raised face. The fusion welding process for the stub end is similar to the liner pipe fusion welding but it utilizes a smaller portable welding machine to allow in or over the ditch welding of the flange stub end to the liner end. A detailed fusion procedure and inspection test plan should be developed for the stub end welding as specified by CSA Z662-19, Clause 13.3.7.
- Stretching out and clamping the liner at the leading end to allow removal of the wireline pull head, cutting the liner back to the required length and butt fusion of the flange stub end adapter. The stretch out length is based on the liner installer experience and judgement. Normally a minimum liner segment length and wireline load is required to allow the necessary stretch length to be achieved without overstressing or over compression of the liner. The length and maximum wireline load specified by the liner installer will vary based on the liner physical dimensions and the method of installation.
- Releasing the clamp to allow the stretched liner with welded on flange stub end adaptor, to contract into the steel host pipe and position the adaptor face up against the steel flange face.

- Fitting metal retaining rings around the liner flanges. These are designed to a controlled thickness to limit compression of the flange adaptor fittings and to prevent flattening of the adaptor flange material under load. The rings also help ensure uniform compression of the flange faces is applied during bolt-up.

Fitting the steel retainer ring and bolt-up of flanges is performed under supervision of the liner installer and normally their trained personnel do the flange assembly, using an air-powered torque wrench. Bolts must be made up in proper sequence and to the torque values specified by the liner installer.

Flange assembly must be properly executed. If the flange bolt loading is too high it could damage the plastic facing on the HDPE flange adaptors and result in leakage. The repair is very difficult to implement as it requires breaking the flange joint apart, stretching the liner end and clamping to allow removal and replacement of the flange adaptor fittings.

Note: Any future breaking apart of flanges and reassembly will require installation of a modified steel retainer ring, to achieve the compression and seal of the existing HDPE flange stub end faces, which are now reduced thickness due to their service time in a compressed state.

5.9 Liner Expansion/Pressure Testing

For all methods of liner installation, after pull-in the liner must be expanded against the steel host pipeline and pressure tested.

The pressure test procedure must fulfill the requirements of CSA Z662-19 (13.2.7). This states a four-hour liner leak test at the maximum design pressure (MAOP) and if the testing pressure is above 2.0 MPa, the test pressure after completion of the four-hour test is lowered to 2.0 MPa and held for an additional four hours.

Note: The intent of the second testing step at 2.0 MPa is to allow relaxation of the liner and better enable flow of any pressure test fluid that could be leaking from a liner breach to the annulus vents for detection.

Typically, the pressure test fluid is water or water with 50 per cent freeze point depressant. Compressed air pneumatic testing is allowed for liners installed in new steel pipelines only and if the new steel pipeline was pressure tested in accordance to CSA Z662-19 Clause 8. The pneumatic liner leak test procedure must be approved by the owner company.

The liner installer should provide their proposed liner expansion and pressure testing procedure to ensure that the rate of expansion used is suitable for the liner given its dimensions and temperatures. The temperature of the expansion fluid must also be considered as in some cases it may be very cold depending on ambient temperature conditions.

During the pressure testing, the vents should be periodically opened and monitored for presence of any fluid flow that would indicate a possible liner breach. Vents should not

be left open while unattended, as a liner breach would result in a release of the pressure test fluid to the environment from the open vent. Testing fluids may contain chemicals such as freeze point depressants or other contaminants harmful to personnel and the environment.

Operators may choose to leave the flanged connections and vents exposed for visual checking for leaks.

The pressure test should be measured, recorded and documented as specified by CSA Z662-2019, Section 8.7.

During pressure testing of HDPE liners, the test pressure may initially drop due to gradual expansion and creep of the liner. Typically, longer pressure stabilization periods are required. Usually if the liner is intact and not breached, the rate of test pressure drop will decline and approach zero as the test proceeds and the liner stabilizes against the steel pipe. In some cases, small amounts of additional test fluid are added to maintain/re-set the specified test pressure and again the rate of pressure drop should decline if the liner is not leaking and the vents show no indication of test fluid flow.

During the pressure test, the venting system may be checked for any evidence of plugging of vents, vent tubing, or vent jumpers. For grooved liners, in some cases, annulus communication checks of lined sections using compressed nitrogen has been performed.

6 Operation

6.1 General

In general, the operation of a HDPE lined pipeline is similar to the operation of a conventional steel pipeline system. However, several unique differences exist that operation and maintenance personnel should be aware of to ensure the HDPE lined pipeline is not operated outside its design limits resulting in degradation or physical damage to the liner.

Training operations staff to increase awareness of unique requirements for operating a lined pipeline system is highly recommended. Field signage can be used to highlight and remind operations staff regarding the locations of lined pipelines.

6.2 Pressure

The pressure control, limiting and relieving systems of lined pipelines are similar to those used for steel pipelines. However, lined pipelines should operate at a steady operating pressure without excessive routine pressure cycling.

Automatic closing ESD valves placed at each end of a lined pipeline to maintain liner pressure during unplanned field or plant shutdowns will help resist liner buckling or collapse that might otherwise occur from an uncontrolled sudden depressurization.

Operators need to be made aware of the unique requirements around operation of a lined pipeline. Some of the main aspects include

6.2.1 Start-Up

Immediately prior to starting up lined pipeline systems in gas or multiphase pipelines, any accumulated pressure should be bled off at all the vents. As soon as the pipeline is up to operating pressure, the pressure at each vent point should be checked and recorded. This should be repeated after 48 hours' operation.

6.2.2 De-Pressurizing

Before de-pressurizing the pipeline, the vent points should be opened for at least one hour.

The rate at which the vents can relieve the gas trapped in the annulus should be monitored to ensure that the venting rate during de-pressurization is sufficient to prevent a positive pressure difference between the annulus and the pipeline, i.e. at no time during de-pressurization should the annulus pressure be greater than the internal line pressure.

For higher pressure pipelines, as the internal liner pressure is lowered, some increased venting may occur. This is likely due to the liner relaxing slightly and allowing gases to increase their flow to the vents.

Recommendation:

The operator should specify a procedure for routine de-pressuring of lined pipelines that includes a maximum rate and doing in stages with specified hold points.

6.2.3 Vacuum

Awareness and preparation of vacuum conditions is important in operation of a HDPE lined pipeline. Liner failures due to vacuum have occurred and typically appear as a collapsed liner. Typically, vacuum itself is not the only cause of a liner collapse but may act as a trigger to initiate a collapsed liner.

Contributing causes of vacuum collapse of liners include following:

- Topography elevation variations along the pipeline right of way.
- Pipeline system stoppage of flow, planned or unplanned.
- Injection well drawdown on the pipeline during shut downs.
- Liquid fill or displacement procedures of pipelines.
- Absence of a back pressure control valve (BPCV).
- Inadequate setting of a BPCV to account for topography elevation changes.

- Higher temperature operation, e.g. above 60°C, significantly reduces liner physical properties such as Young's modulus, that reduces resistance to buckling and collapse.
- Operation with annulus vent valves left open or opening vents while liner is under vacuum.

6.3 Temperature

A critical aspect of liner design is the operating temperature. HDPE liners are significantly affected by temperatures as discussed previously in Section 4.

Temperature will affect the degree of liner swelling from liquid hydrocarbons and rate of gas permeation. Temperature may also affect the liner's physical properties.

In cases where liner collapse is a concern, temperature plays a key role. As discussed in Section 3.3, the liner design must consider the maximum operating temperature and that consideration must be carried forward through to the operating procedure for the lined pipeline.

In some cases, operators must limit the operating temperature to reduce the risk of liner buckling and collapse. The temperature limit may be lower than the liner materials' capability. For example, based on its design, a HDPE lined pipeline may require limitation to a maximum operating temperature of 45°C, where the same liner material in different fluid service or operating conditions may be suitable to 60°C or 70°C or higher operating temperatures.

Therefore, it is very important to operate lined pipelines within their maximum design temperature. In cases where pipeline service fluids are heated at the inlet, suitable alarm controls should be installed and set accordingly. It is not recommended to operate above the design temperature limit even for short durations, such as for pipeline start-up.

6.4 Pigging

Pipelines with liners do not usually require pigging. However, if the pipeline requires pigging to remove fluids or solids, then only suitable approved pigs shall be used.

Pigging is possible in lined pipelines; however, pig materials should be restricted to softer rubber cups (80 or 60 durometer) or foam styles without metal components.

If the need for routine pigging is identified at the design stage, consideration should be given to removal of the internal fusion weld beads.

An important factor to consider when selecting a pig is the different internal pipe diameters that exist for lined pipelines. It should not be assumed that a pig sized for steel pipeline is also suitable for smaller internal diameter lined pipelines.

In general rubber ball style pigs or cupped pigs with solid metal bodies should not be used for lined pipelines.

Recommendation:

In all cases, the liner installation company or an experienced pipeline pig supplier/manufacture should be consulted for pigging procedures and recommended pig products suitable for lined pipelines.

6.5 Chemicals

The addition of any chemicals to a lined pipeline should always be done with caution. Prior to adding a chemical, it should be reviewed for its effects on HDPE with the liner material supplier.

In most cases the effects of chemicals on HDPE are well known and consulting a chemical resistance chart is a good place to start. Most HDPE manufacturers or suppliers publish such charts and liner installation companies can provide them as well.

In general HDPE is resistant to most chemicals such as waters, acids, bases, alcohols and amines.

The chemicals of most concern are liquid hydrocarbon solvents. Crude oil can affect HDPE properties due to absorption, however the more aggressive chemicals are aromatic or cyclic chain hydrocarbons, such as BTX (benzene, toluene, and xylene), cyclo-pentane, cyclo-hexane, etc. These chemicals are known to cause increased swelling and loss of mechanical properties for HDPE, as discussed previously in Section 3.6. The effect of these hydrocarbons, on physical properties of HDPE, may be reversible over time only if the chemical exposure is removed and de-absorption of the chemical occurs. Generally, lower concentrations of these hydrocarbons, below approximately 5 per cent reduces effects compared to higher concentrations.

Operating situations should be avoided where lined pipelines are filled with aggressive solvents such as BTX and then allowed to soak for long durations.

Methanol has been associated with causing corrosion behind the liner in lined sour gas pipelines when added in liberal rates to prevent hydrate formation. Methanol vapor permeates through HDPE like H₂S and where both gases condense in the annulus, it can lead to corrosion damage. This effect is also discussed in Section 3.7 and in the referenced documents.^{6,7,8,9}

6.6 Flow Velocity

The maximum flow velocity should be determined on an individual project basis, based on the fluid characteristics including whether any abrasive solid content is present and in consultation with the liner manufacturer.

In general, the typical values in Table 6-1 represent suggested maximum flow velocity guidelines for HDPE lined pipelines and are based on standard HDPE grades and service fluid without abrasive solid content.

Table 6-1 Typical Maximum Recommended Flow Velocity ¹

| Service | Normal Flow (m/s) | Maximum Flow (m/s) | Maximum Intermittent Flow (m/s) |
|---------|-------------------|--------------------|---------------------------------|
| Liquid | 1-8 | 10 | 15 |
| Gas | 5-15 | 20 | 40 |

Note 1:

The above velocities are based on the assumption that no hard particles are present in the flow. Hard particles may be acceptable for HDPE lined pipelines but the potential erosion rate of the liner must be reviewed with the liner supplier.

6.7 Annulus Vents

Venting procedures are required to provide liner integrity checks and to prevent liner collapse that tends to occur most often during process upset conditions (large pressure fluctuations) or shut downs. To lower risk of liner collapse, regular venting is especially required when gases are present in the pipeline service fluid. Venting is less critical for liquid filled pipelines in terms of collapse prevention, but oilfield produced water pipelines may still contain low levels of dissolved gases that may permeate and accumulate in the annulus. Therefore, all lined pipelines, regardless of service fluid type, require periodic venting to check liner integrity.

In general, annulus vents should be opened for the following conditions:

- Prior to changes in the operating conditions.
- Immediately (e.g. one hour) prior to de-pressuring.
- Routinely during operation to evacuate the permeated gas accumulated in the annulus and monitor liner integrity.

Vent observations should be recorded in a log and should include observations such as: date, length of time vent remained open, vent initial and final pressures, description of volume of gas or if any liquids observed and other general observations. Hydrocarbon liquids can also be vented with gas in multiphase lined pipelines.

Where a liner breach is suspected, the operator may catch a sample of annulus fluids from vents for analysis and comparison to the service fluid.

CSA Z662-19 specifies requirements for routine checking of annulus vents by pipeline operators to look for pressure buildup or indication of liner leakage. The frequency of the vent checks is determined by the HDPE lined pipeline operator, however a maximum three month interval is recommended.

The venting schedule should be reviewed by the operator regularly and possibly revised based on observations made. Having the log entries would be helpful in conducting the review.

In some cases involving more critical services such as high-pressure sour gas pipelines, venting systems have been jumpered and tied into gas scrubbers to allow continuous annulus venting at end points. These more elaborate venting systems may be equipped with vent pressure indicators and be tied into SCADA systems, to allow real time monitoring of annulus pressures. ⁸

If toxic gases such as H₂S are present in the annulus, the operators should develop special venting procedures that address safety and environmental concerns.

In some cases, operators have used portable or permanently installed gas scrubbers to remove H₂S from vented gas.

Some industry operating companies and liner suppliers are evaluating other possible methods to monitor or relieve liner annulus interstitial pressures such as automatic

pressure reducing valves or other specialty devices designed to automatically relieve or vent the annulus pressure, once a preset maximum pressure differential across the liner is reached.

Note: Automatic venting devices should be reviewed and determined to be “fail safe” in that if any sustained fluid flow is detected they will close off and prevent an uncontrolled release from the lined pipeline.

6.8 Vent Maintenance

Vents should be kept free from deposits that can plug the vent tubing. A blocked vent, tubing or fitting should be cleaned with low-pressure fluids such as water, diesel or nitrogen only. The use of rods, steam jets or sharp tools for cleaning should not be used.

During cold weather operation, care should be exercised in that annulus vents stations may become plugged off due to freezing. Therefore, no observed vent pressure during checks may not mean that no annulus pressure buildup is present.

The use of alcohol, such as methanol or ethanol, diesel, or the application of heat may be required to clear frozen off vents and tubing.

Note: As discussed previously in Sections 3.7 and 6.5, methanol injection at vents to maintain flow has been associated with annulus corrosion mechanisms and has been reported in HDPE lined sour pipelines.^{6,7,8,9}

Recommendation

Use of methanol injection into annulus vents for clearing or cleaning must be cautiously reviewed by operators and only used to clear annulus vents after technical assessment of its potential effects on annulus corrosion of the steel carrier pipe.

6.9 Repair

Lined pipes and fittings should not be repaired by welding, since heat could cause damage to the liner. If damage occurs to a component of an installed lined piping system, the damaged component should be replaced.

Liner repair should generally always be undertaken in conjunction with the liner installer. The liner installer has expertise and specialized equipment required to evaluate and execute the type of liner repair required.

Industry experience has shown that liners can buckle and form a collapse lobe at or near to the downstream flanged connection. The lobe may extend and tear the HDPE flange stub end adaptor that requires it and, if required, a short length of collapsed liner to be replaced. See Section 7.6, Figures 7-1 and 7-2.

Where the liner flange adaptor is damaged, the liner may be repaired by stretching the liner using a wireline winch to expose the flange adaptor and a short section of liner pipe, to allow clamping. Once clamped the wireline may be disconnected to allow the damaged flange stub end adaptor fitting and short liner length to be cut-off and

replaced. This allows a repair to be performed without requiring the removal of the entire liner section.

The liner wall must be assessed for evidence of contamination from service fluids such as crude oils. Such contamination can negatively affect fusion weld quality, typically causing low fusion strength or excessive porosity in the weld due to gases that can flash off during the fusion welding process as discussed previously in Section 5.5.2.

In cases where a liner collapse has occurred, the liner segment can be pulled out and replaced. Liner segment removal can prove difficult and may require the pipeline segment to be cut in one or more locations in order to remove the liner in shortened sections. The liner retrieval procedure should be developed by an experienced liner installer.

Leakage at flanged connections can be remedied by re-torquing of flange bolts to the specified values. Care shall be taken not to exceed torque values. In such cases, the steel retainer ring width may require adjusting and resizing to account for compression of the flange adaptors.

Note: When breaking apart flanges the steel retainer rings will require resizing or replacement to account for permanent compression of the HDPE flange stub end faces.

6.10 Operational Procedure

An operational procedure should be developed for all HDPE lined pipelines and flowlines by the operator in consultation with the liner supplier. This procedure should be based on the HDPE liner design and as a minimum address the following aspects:

- System description
- Normal operating envelope and maximum limits
- Venting procedure and frequency
- Pigging
- Start-up procedure.
- Routine operations
- De-pressurizing procedure

7 Integrity Assessments

7.1 Non-Destructive Examinations

The methods for localized non-destructive examinations (NDE) of HDPE lined pipelines are essentially the same as methods used for unlined steel pipelines.

In some cases, radiography has been used to spot check lined pipe for signs of liner collapse or to locate internal corrosion of the steel carrier pipe.⁸

Liner collapse often has occurred immediately adjacent to the downstream flange connection so excavation of this area and the use of radiography to check for liner collapse is possible.

Ultrasonic inspection can also be used to determine steel pipe remaining wall thickness at key areas, such as near liner connection flanges or at areas of liner failures.

7.2 Pressure Testing

To verify the integrity of a liner the use of a pressure test may be considered. When pressure testing, it is prudent to maintain the pressure test at or below the pipeline design pressure and carefully monitor annulus vents for signs of liner leakage.

7.3 Internal In-line Inspection - Liner In-place

In recent years, technology has evolved for the inspection of HDPE lined pipelines using internal in-line inspection logs (ILI) techniques.

Magnetic flux leakage (MFL) or ultrasonic testing (UT) technology ILI tools cannot be used due to the presence of the non-metallic HDPE liner. The liner is an electrical insulating and non-magnetic material that is not bonded to the inside of the host pipe and also is acoustically different from the steel carrier pipe. This prevents either MFL or UT technology inspection pigs from being used.

For HDPE lined pipelines, one ILI method employed utilizes the remote field testing (RFT) inspection principle. This technique does not require any direct contact of the ILI tool with the steel pipe wall. The RFT inspection tools can be propelled through the pipeline with water for longer length pipelines or pulled through shorter pipelines, up to approximately 3 km in length, using a wireline tether.

Various operators in western Canada have utilized the RFT approach for conducting ILI inspections of HDPE-lined, concrete-lined and epoxy-lined pipelines. 6,10,11,12

Note: Riser and interconnected piping, including valves, should have compatible internal diameter to allow for future pigging, including running of inspection tools (ILI) or be prepared to install temporary spools to allow ILI surveys.

In some cases internal caliper survey tools have been run inside lined pipelines to look for anomalies such as reductions in the liner internal diameter (bulges) that may be indicative of corrosion activity behind the liner or liner breaches.

7.4 Internal Inline Inspection - Liner Removed

When liner segments are pulled out for repair or replacement it allows for inspection of the steel carrier pipe section. In these cases, visual or spot NDE tests can be performed.

Tethered ILI tools based on MFL principles can also be run on wireline and pulled through the pipeline section when liner section is removed.

For localized visual internal inspections, possibly up to approximately 15 meters, extendable boroscope optical devices can be used when flanges are broken apart to visually inspect liner for signs of buckling or collapse.

7.5 Integrity Management

Similar to unlined steel pipeline systems, the integrity management of HDPE lined pipeline systems must be considered. The integrity of the steel carrier pipe is integral to successful long-term operation of a lined pipeline system.

In industry, failure due to internal and external corrosion of HDPE lined pipelines has occurred. Failure due to internal corrosion most frequently has occurred where the liner has breached but also in some cases where it has not.

Knowledge of the general failure mechanisms experienced in a local area operating history can also be incorporated into integrity management planning.

Operating service factors that can increase the probability of liner failure mechanisms occurring include:

- High temperature operation increases risk to liner and exterior pipeline coating.
- Cyclic pressure operation, rapid depressurizations, especially where gases may be trapped in the annulus.
- Liquid hydrocarbon streams such as crude, condensate.
- Gas gathering or multiphase are at increased risk of liner collapse.
- Topography elevation changes can lead to vacuum.
- Lack of venting in gas containing applications.

A key advantage in managing HDPE lined pipelines is that the annulus vent checks may detect a liner breach and enable repair to be planned and implemented before significant corrosion damage to the carrier pipe occurs.

Where unlined steel piping segments are used for risers, corrosion of the steel piping must be considered for integrity management. NDE inspections of unlined risers can be considered.

External corrosion has led to failure of lined steel pipelines where the carrier pipe ruptures under high pressure and the liner cannot withstand the pressure and also ruptures.

7.6 Liner Damage Mechanisms



Figure 7-1 End View of Liner Tear and Collapse at Flange Adaptor. Photo credit: Cormetrics Ltd.



Figure 7-2 Side View of Liner Tear and Collapse at Flange Adaptor. Photo credit: Cormetrix Ltd.



Figure 7-3 Liner Fracture at Collapse Lobe. Photo credit: John Baron



Figure 7-4 Typical Liner Collapse Lobe. Photo credit: Cormetrix Ltd.

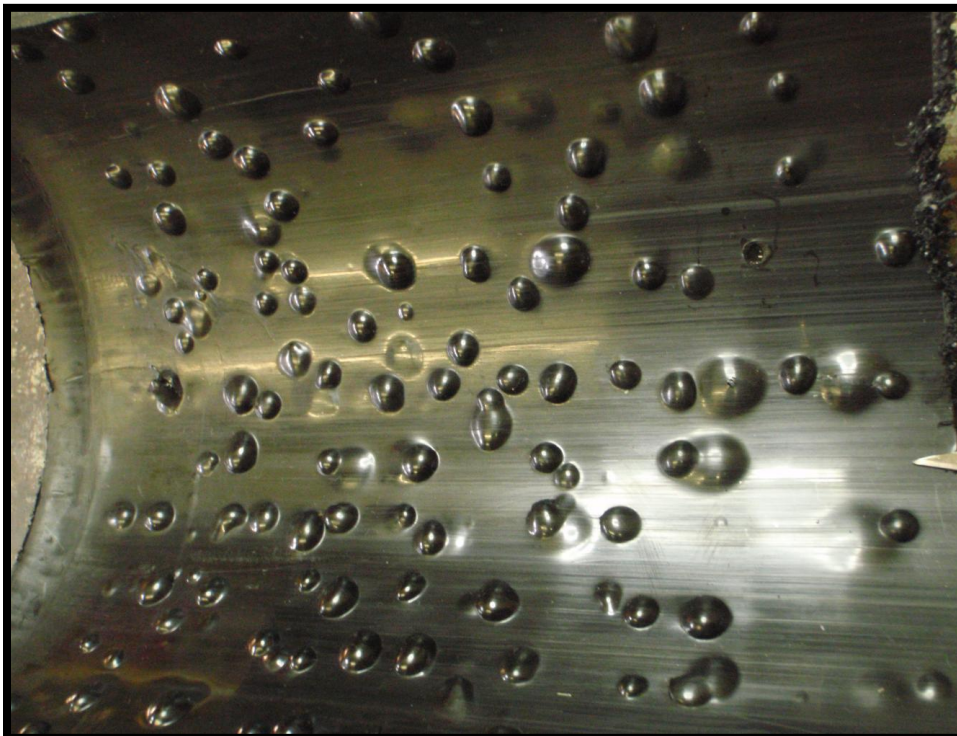


Figure 7-5 Liner Surface Blisters. Photo credit: Cormetrix Ltd.

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