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High Density Polyethylene Liners for High Temperature and Gaseous Applications

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ABSTRACT

The process of utilizing an oversized high density polyethylene (HDPE) liner to protect pipelines from internal corrosion has been used successfully for over 25 years. Limitations of use have been placed on the technology, however, in certain applications due to higher temperature service and/or the presence of vapor within the pipeline.

All HDPE plastic pipe liners used in gaseous applications are susceptible to the permeation of gas into the annulus between the liner and the carbon steel pipe. Smaller molecules such as hydrogen are more prone to permeation than others, and all molecules tend to permeate at greater relative rates under higher pressure and temperature conditions. The Safetyliner™ HDPE liner system is designed to provide a more effective and efficient method of managing the permeated gases that migrate into the annulus.

Safetyliner™ offers all of the same polyethylene lining protection of a smooth-wall HDPE liner, but differs in that a series of small grooves exist on the outside of the liner. The grooves in the HDPE liner pipe provide a path for any gases that may permeate the liner. These gases are channeled along the grooves to monitoring vents positioned near the pipeline connections. This monitoring and venting can be manually operated or fully automated to keep annular pressure below the level desired to prevent integrity problems and to allow quick detection of any possible leak should a breech in the HDPE liner occur.

This paper examines and details the theory behind the Safetyliner™ HDPE liner as well as provides an example of use in a real world application.

1. INTRODUCTION

Internal corrosion of carbon steel pipelines has long been a problem for the oil and gas industry that has required financial investment to combat along with operational and maintenance diligence. Even then, inspection of pipeline internals is difficult and costly to achieve leaving an ongoing risk of leaks and environmental damage. While there are many alternatives to preventing, mitigating, controlling, and allowing for internal corrosion, the use of thermoplastic liners has proven to be very effective at internally protecting carbon steel pipelines and providing significant life cycle cost advantages. High density polyethylene (HDPE) is the traditional thermoplastic of choice for polymeric lining; however, when high temperature and gaseous applications are encountered, other more exotic polymers and polyamides have been used to varying degrees of success but usually at significantly higher material and installation costs. A possible solution exists that allows for the use of oversized thermoplastic lining in these more extreme conditions.

2. HIGH DENSITY POLYETHYLENE LINER HISTORY

HDPE liners have been used for decades to line carbon steel pipelines for protection against a corrosive or abrasive attack. HDPE liners utilize a low cost and readily available raw material – typically specified as ASTM PE-3408 or PE-4710 or ISO PE-100 – which also is chemically resistant across a broad range of chemicals, and its physical properties are often favorable for increased resistance to erosion compared to bare carbon steel. Additionally, the polymeric nature of HDPE and the resulting properties lends itself to use as a means of rehabilitating existing pipelines since HDPE is excellent for bridging holes and spanning gaps often caused by corrosion and erosion. Finally, in addition to reducing or eliminating corrosion within the carbon steel pipelines, HDPE lining can also improve the flow characteristics of the pipeline because although there is a slight reduction in pipeline inside diameter (ID), the absolute roughness of HDPE is approximately 30 times smoother than new carbon steel.

While HDPE has been used for "slip lining" applications, this process is essentially using an existing host pipe as a conduit for a smaller diameter, fully structural HDPE pipe. With a hoop strength that is drastically lower than carbon steel, HDPE pipe must be very thick to contain increasing amounts of pressure, and the pressure rating of the HDPE is significantly reduced in hydrocarbon service and at temperatures above ambient conditions. As such, the use of interactive, tight fitting HDPE liners has been developed and utilized in higher pressure corrosive applications often found in oilfield pipelines. These applications typically include crude oil pipelines and pipelines containing oil emulsions or three phase flow, produced water and water injection/disposal service, sour and wet gas pipelines, and CO_2 production and injection lines. Other pipeline applications such as brine service, water and acid wastewater, and chemical slurries are also excellent applications for HDPE liners.

Traditionally and predominately, smooth wall HDPE liners have been utilized to internally protect pipelines. In fact with smooth wall liners, the only difference between HDPE liner pipe and stand-alone HDPE pipe is the wall thickness. By-and-large, this has made it easier for HDPE pipeline manufacturers to successfully adapt to production of HDPE liners because the only output variable is wall thickness. The smooth wall on the outside of the HDPE liner allows for the tightest possible fit against the inner wall of the host steel pipe which means that the smallest possible "micro-annulus" is formed between the HDPE and host steel.

3. DESIGN

For interactive, tight fitting HDPE liners, it is important that the liner is custom sized for the pipeline specifications under consideration. The HDPE liner is designed and produced such that the outside diameter (OD) is larger than the ID of the host pipe to be protected or rehabilitated. Based on the ID of the host pipe, the appropriate HDPE liner size is known, and the HDPE wall thickness can be chosen based on extrusion capabilities and the desired service application. To save raw material cost of the HDPE liner, the thinnest practical wall thickness is chosen; however, physical limitations of the HDPE extrusion process is often the determining factor in allowable wall thickness. The industry strives to produce interactive HDPE liners with a ratio of OD to wall thickness (called the "Dimensional Ratio" or DR) of 41.

4. INSTALLATION

Before field installation can begin, a new or existing host steel pipeline is sectioned to allow for the insertion of the HDPE liner. Once the HDPE liner is manufactured and delivered to site for the field installation, the short (12 m or so) individual liner lengths are thermally fused into long, monolithic sections particular to each sectioned length of host pipe previously prepared to accept the HDPE liner. A blow-down pig and sizing plate are then attached to a steel cable and sent through a section of the host pipeline. Once the steel reaches the other end, the section of pipe has been cleared for HDPE liner installation since the steel sizing plate confirms a clear path, and the cable is attached to a fabricated pull-head on the corresponding length of HDPE liner pipe.

A specially constructed winch or wireline then pulls the HDPE liner through a specially designed diameter reducing mechanism. This mechanism may be either fixed or may have moving functionality such as with the roller reduction process. This mechanism is positioned at the insertion end of the host pipe usually in direct line with the host pipe entry point either above or below grade. The HDPE liner is temporarily compressed radially as it passes through the diameter reducing mechanism, and it is also placed under axial tension via the wireline pulling it through the equipment and into the host pipeline. Both of these effects cause temporary reduction of the HDPE liner OD so that it may fit inside the otherwise impossibly small ID of the host pipe. Even after the HDPE liner pipe exits the diameter reducing equipment, the thermoplastic properties of HDPE as well as the continuing axial tension of the wireline prevents the HDPE from immediately returning to its original OD.

Once the HDPE liner has been completely installed inside the host pipe, the axial tension is released, the liner pipe begins to expand, the HDPE liner returns to its near original OD, and a tight fit against the inner wall of the host pipe is created. Following relaxation of the liner pipe, custom manufactured HDPE flange-fittings ("stub ends") are thermally fused to each end of the lined section. The flanged sections and the HDPE stub ends isolate each installed, lined section from one another. A steel spacer ring is placed between the raised faces of the steel flanges and around the HDPE stub ends to help ensure a leak free connection. Monitoring vents are placed near each flange to confirm that the monolithic HDPE pipe lining system is intact and the inside of the pipeline is completely and continuously isolated from the host pipe and the monitoring vent. The two steel flanges are then positioned together and the line is tested and bolted-up before placing in service. A representative drawing of a lined section is found in **Figure 1**.

5. ACCEPTANCE AND APPLICATIONS

This installation method has been proven over decades of projects around the globe, and as more and more projects have been completed, the acceptance and use of HDPE liners have become more prevalent. This has also led to the use of HDPE liner in more services and applications as well as more severe operating conditions. Furthermore, as more enhanced oil recovery methods have been utilized to capture more oil, these operations introduce inherently corrosive conditions. Not only are secondary recovery methods increasing, but tertiary methods such as miscible flooding using high pressure, high temperature (supercritical) CO_2 injection are also on the rise. This is in addition to the production of higher temperature, higher gas production, and higher sulfur content wells which all lead to higher rates of internal corrosion.

6. ALTERNATIVES

To fight this trend and the inevitable onslaught of internal pipeline corrosion, there are numerous options available. The use of corrosion resistant alloys (CRA) for pipeline construction is a proven method to ensure the long life of an oilfield's production infrastructure. Along with its documented effectiveness, it is also well known to be one of the most expensive methods to combat corrosion. Instead, some operating units prefer to install carbon steel pipelines along with chemical injection facilities to continuously inject corrosion inhibitors. Not only does this introduce capital and operating costs to keep the chemical tanks full and injection equipment functional, but it has proven nearly impossible to optimize injection rates especially when operational upsets are encountered. Although effective, much of the expensive corrosion inhibitor chemical is wasted in the hopes of controlling internal corrosion. For some applications, fusion bonded epoxy (FBE) has been used to fight internal corrosion, and although carbon steel pipeline life is extended beyond that of bare steel, problems have been reported with (a) less than adequate protection of the welded joint area, (b) existence of holidays, thereby exposing pinhole sized areas of the carbon steel, and (c) portions of FBE flaking off the host pipe, thereby exposing large areas of bare steel and possibly causing plugging issues downstream of the pipeline.

7. HIGH TEMPERATURE AND GASEOUS APPLICATIONS

A problem most often cited with smooth walled, tight fitting HDPE liner in more severe, higher temperature, and gaseous applications is the threat of liner collapse when operational upsets cause significant pressure fluctuations. This collapse possibility is caused by the permeation of gaseous molecules driven by the pressure differential between the pipeline and the HDPE/steel micro-annulus over time and at elevated temperatures. All HDPE plastic pipe liners used in gaseous applications are susceptible to the permeation of gas into the annulus between the liner and the carbon steel pipe. Smaller molecules such as hydrogen are more prone to permeation than others, and all molecules tend to permeate at greater relative rates under higher pressure and temperature conditions. The higher temperatures provide individual molecules more energy to permeate through the solid HDPE material and the partial pressure differential creates a concentration gradient, hence a greater driving force for the molecules to migrate through the HDPE.

The gaseous molecules will continue to permeate until equilibrium is reached between the micro-annulus and the pipeline. If the pressure of the pipeline decreases significantly and quickly enough, that is at a greater rate than the molecules can permeate back from the micro-annulus to the pipeline, then the gas molecules in the micro-annulus will expand to reach a new equilibrium assumed to closely follow the ideal gas law of $PV = nRT$. As the pressure decreases, the volume must increase at a constant temperature and number of molecules in the micro-annulus. The expansion of the gas in the annulus will exert force on the HDPE liner in the direction away from the host pipe and toward the center of the pipeline. There are certain design characteristics and physical properties of the HDPE liner that can prevent collapse, namely thickness of a smooth wall liner, but if there are enough molecules in the micro-annulus and if the pressure drop of the pipeline is not adequately controlled, the HDPE liner will be forced away from the host pipeline.

Empirical evidence has shown that on many occasions, a first collapse may be relatively small and insignificant such that it is not noticeable and does not materially affect pipeline operation. When the pipeline is returned to normal operating pressure, the increased pressure forces the HDPE liner back toward the host pipe. However, the tight fit of the liner is not as tight as the initial installation such that the micro-annulus has grown in volume. This then allows more molecules to permeate into the larger micro-annulus, and should another operational upset and uncontrolled pressure drop occur, the increased number of molecules will need to expand to fill the larger void. Subsequent collapses will become larger and more pronounced to the point that deleterious operational effects may be incurred.

The monitoring vents placed on the line during installation and used in the leak testing process can be utilized to vent gas that has permeated the HDPE liner (**Figure 2**), and this has been the standard method utilized for smooth wall liners when installed in gaseous applications prone to operational upsets. The requirement for this type of operation is to open the vents occasionally to release any permeated gas and confirm that the HDPE liner has not been compromised such that a physical leak is present. Because of the oversize nature of the tight fitting HDPE liner, the path for the gas to migrate along the micro-annulus to the monitoring vents could be so tortuous such that they may remain trapped inside despite the fact that the monitoring vent opens the micro-annulus to atmospheric pressure. Weld bead penetration at the joints is one example of where and how permeated gas could become trapped.

8. THE SOLUTION

A new technology in HDPE lining for high temperature and gaseous applications was therefore developed. This technology increases the wall thickness of an HDPE liner so that grooves may be created equally on the outside surface along the entire length of the installed liner (**Figure 3**). These grooves not only allow an area for the molecules to collect once they have permeated the HDPE wall, but they form an annular path or unobstructed "freeway" along the entire HDPE lined section to the existing monitoring vents as previously shown in **Figure 2**. In the area of the monitoring vents at each end of the pipeline section, a large circumferential groove is cut on the outer surface of the HDPE liner to connect all of the lateral grooves.

By virtue of increasing the wall thickness to accommodate the grooves, the inherent collapse resistance of the HDPE liner is also increased exponentially according to:

$$P_c = 2.334E(t/R)^2$$

where **Pc** is the collapse pressure (bar), **E** is the HDPE liner Young's modulus (MPa), **t** is the liner wall thickness (mm), and **R** is the average radius of the liner (mm). Since **E** decreases as a function of temperature, the collapse pressure (hence, resistance of the HDPE liner to collapse) would also decrease without an increase in wall thickness. This increased wall thickness combined with the grooves to allow complete venting of the permeated gases is the most advanced and accepted method of utilizing high density polyethylene liners in high temperature and gaseous applications.

9. ADDITIONAL DESIGN AND IMPLEMENTATION IMPROVEMENTS

Although with the grooved liners there is a path to vent the permeated gas, by design there is also a larger void for the permeated gases to collect. This fact is an important consideration since an uncontrolled pressure drop in a pipeline using a grooved liner would lead to a larger expansion of the permeated gases. As such, it is important to diligently monitor and vent a grooved liner lined pipeline. The most common method of doing this is by manual operation by pipeline personnel as done for the smooth walled HDPE liners. In areas that are difficult to access or are in environmentally sensitive areas, small CRA pipes may be installed on adjacent monitoring vents to "jumper" the isolating stub end flanged connections. This is illustrated in **Figure 4** with a representative grooved HDPE Safetyliner™ forming the annulus path between the host pipe and area **"A"** showing the CRA jumper with an additional valve for monitoring and/or venting purposes. Because there is a clear path from one end of a grooved liner installed section of pipe to the other end, this jumper can be used to connect one section of lined pipe to another section until a more suitable point of disposition is available.

For highly concentrated sour gas, these jumpers may be used to allow the permeated gas to flow to collection points such as stand-alone sweetening pots or small compressors (**Figure 5**) to force the gas over long distances to a central treatment facility. Furthermore, environmental and safety concerns can justify the installation of automatic detection devices that monitor annular pressure to ensure that the permeated gas removal system is functioning properly and/or to make sure that the integrity of the grooved HDPE liner has not been breeched.

At CO_2 production facilities, grooved liners are often the internal corrosion protection method of choice, and the pipelines can often be found with the monitoring vents open to the atmosphere. This prevents any buildup of permeated CO_2, and the small amount of permeated gas is considered to be no more than the amount of CO_2 that naturally seeps up through the ground from the CO_2 reservoirs. In areas where Water-Alternating-Gas is used for enhanced oil recovery with miscible CO_2 flooding, there is usually no significant concern for venting of the permeated gases either, and grooved liners are often used because of the higher temperature and gaseous conditions.

The use of grooved HDPE lining of carbon steel pipelines in CO_2 service continues to be one of the most reliable and cost effective means of extending pipeline lifetime, often beyond the useful life of a well. It is a "fit and forget" solution, and the following is a description of just such an application of grooved HDPE lining in a CO_2 well injection environment.

10. AN APPLICATION - CO_2 INJECTION AT YATES FIELD IN IRAAN, TEXAS

A thousand feet below the canyons and brushland of the TransPecos region of West Texas lies a vast sea of oil known as Yates Field. Discovered in 1926, it holds the second largest remaining oil reserves in North America.

Marathon Oil and its predecessor companies and partners operated the field for more than 70 years before selling their interests to Kinder Morgan Energy Partners in 2003.

The field, which covers approximately 26,400 acres or almost 41 square miles, has to date yielded approximately 1.5 billion of the 5 billion barrels of crude oil it holds.

Energy companies typically must invest substantial amounts to lift oil from the ground and move it up to surface. Yates Field has now passed its peak production of 125,000 barrels/day, today producing approximately 27,500 b/d. It has remained viable through enhanced recovery methods, including water floods, nitrogen injection and, more recently, CO_2 injection.

Kinder Morgan currently has about 650 current active injection and production wells, approximately 20 percent of which are used to inject water or to re-inject produced CO_2 into the reservoir. These recovery agents act as both a pressurizing medium and a viscosity-reducer, enabling the oil to flow more rapidly through the earth to the producing well. The producing wells lift the oil, water and gas mixture to the surface. CO_2 injection enhances production and is expected to extend the field's life for many years to come.

Extending the field's life, however, also means extending the life of the infrastructure needed to operate it. The corrosive fluids running through its labyrinth of pipelines have taken their toll.

By the mid 1980s, Marathon Oil had begun a rehabilitation program to line corroded pipes already in the ground, including water injection and other lines used in secondary recovery. By the time Kinder Morgan purchased the operations in 2003, a total of 44,400 linear feet of new and existing pipe at Yates

Field, ranging from 6 to 16 inches in diameter, had been lined with HDPE liner. When Kinder Morgan assumed ownership later that year, it continued the program, lining new water injection lines, as well as rehabilitating unlined pipes suffering from internal corrosion.

When Kinder Morgan decided to increase CO_2 injection for tertiary recovery, another application for HDPE lining emerged. Specifically, after CO_2 is added to a reservoir, the fluid extracted – a highly corrosive mixture of oil, water and gas – travels through a flow line to a nearby production station, where the three elements are separated. Due to the known permeation of CO_2 through HDPE especially at elevated temperatures and pressures, the use of grooved HDPE liners is warranted. In recent years, a total of 18 miles of pipe ranging from 4 to 24 inches in diameter have received HDPE liners at Yates Field which illustrates the continued successful implementation, installation, and operation of pipelines utilizing a grooved HDPE lining system.

More than helping to assure the integrity of the piping infrastructure, the HDPE lining program at Yates Field has also yielded other benefits related to safety and environmental compliance.

Considered a "star" among oil production sites in the U.S., Yates Field was the first oil field in the nation to be recognized by OSHA for its Voluntary Protection Program because of the high importance management places on both safety and environmental issues in an effort to achieve operational excellence. To receive this recognition, Kinder Morgan management documented their plans for continuously improving the safety at the site – which includes, in part, the successful use of the HDPE lining system.

11. SUMMARY

All HDPE plastic pipe liners used in gaseous applications are susceptible to the permeation of gas into the annulus between the liner and the carbon steel pipe. Smaller molecules such as hydrogen are more prone to permeation than others, and all molecules tend to permeate at greater relative rates under higher pressure and temperature conditions. The grooved HDPE liner system is designed to provide a more effective and efficient method of managing the permeated gases that migrate into the annulus. Furthermore, it offers all of the same polyethylene lining protection of a smooth-wall HDPE liner, but differs in that a series of small grooves exist on the outside of the liner. The grooves in the HDPE liner provide a migration path for any gases that may permeate the liner. These gases are channeled along the grooves to monitoring vents positioned near the pipeline connections. This monitoring and venting can be manually operated or fully automated to keep annular pressure below the level desired to prevent integrity problems and to allow quick detection of any possible leak should a breech in the HDPE liner occur.

The use of oversized HDPE liners to protect pipelines from internal corrosion has been used successfully for over 25 years. With the advent of thicker, grooved liners and an appropriate monitoring and venting system and operation plan in place, there is a greater likelihood of overcoming the limitations previously considered for the use of HDPE liners in applications of higher temperature service and/or the presence of vapor within the pipeline.

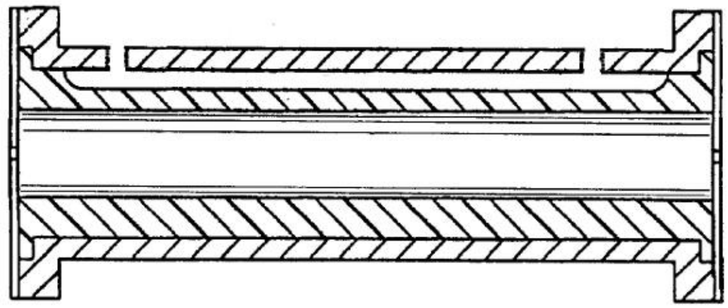

Figure 1 – Internally HDPE Lined Steel Pipe with Monitoring Vent Holes

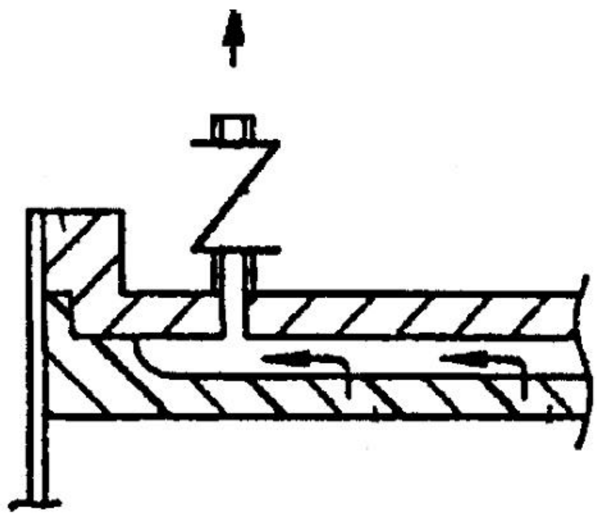

Figure 2 – Venting of Permeated Gas through Monitoring Vent

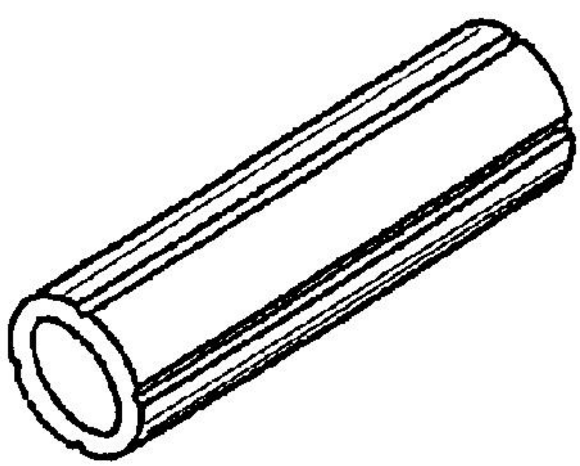

Figure 3 – Representative Grooved HDPE Liner for Use
in High Temperature and Gaseous Applications

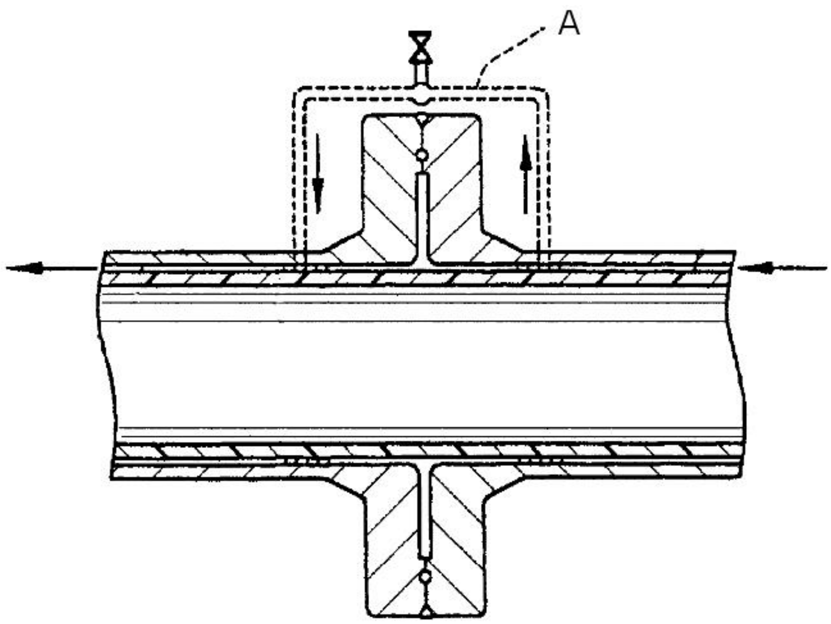

Figure 4 – Example of Monitoring Vent CRA Jumper

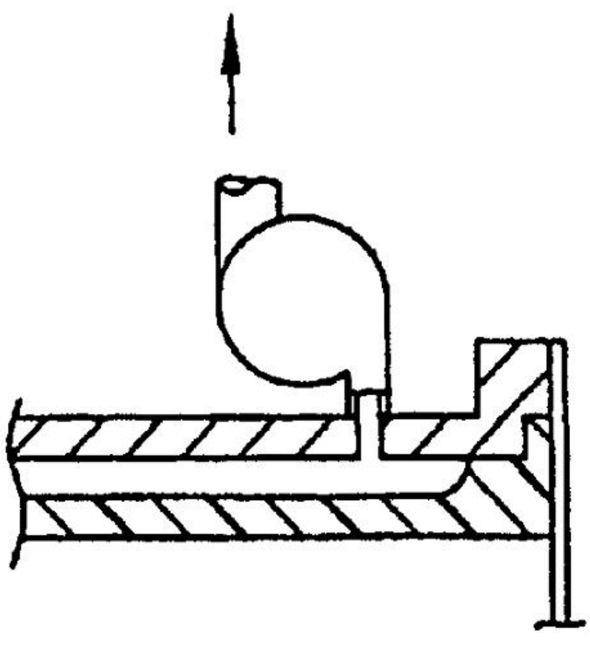

Figure 5 – Example of Permeated Gas Disposition via Compressor