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Thermally Isolated Pipe Support Anchors - Specialized Anchor Improvements for Sulphur Pipelines

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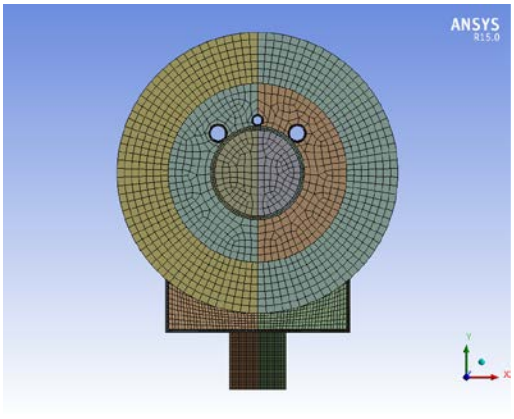
Abstract

To optimize a pipeline Heat Management System for critical services like molten Sulphur, a homogenous thermal profile is absolutely essential for dependable performance. Primarily, this requires a high-integrity and consistent pipeline insulation system. Secondly, it is imperative that any additional metal appurtenances in contact with the pipe wall are eliminated or minimized. Metal-to-metal contact represents an opportunity for unwanted heat loss, and is commonly known as a "heat sink". Heat sinks can cause plugging of Sulphur pipelines, typically at valve, pipe support and anchor support locations. Anchor supports specifically, represent an opportunity for large thermal energy losses due to their mass and thermal conduction of heat from the pipeline service through the steel base frame and directional stops. This paper reviews both the historical and new emerging designs of pipe anchors for use on Sulphur pipelines.

This analysis of the Sulphur pipeline anchors includes new design types, enhanced insulation design, frame design, welding methods and FEA modelling. Field case study results including the use of Distributed Temperature Sensing (DTS) data from fibre optic temperature monitoring throughout the anchor is compared and analysed to understand the heat sink effect of these anchors on a Sulphur pipeline.



The ability to engineer and install "thermally isolated" pipeline anchors is vital to maintaining a homogeneous thermal profile. Using sophisticated thermal Finite Element Analysis (FEA) modelling, new design approaches for pipeline anchors are being introduced which largely eliminate the heat sink effect on a pipeline. This advancement is paramount in the evolution of the next generation of pipeline anchors for Sulphur pipelines.

Keywords: Heat Management System, FEA, DTS, Sulphur Pipeline, Anchor Support, Insulated Pipe Support

Background

Pentair and Rilco Manufacturing have collaborated on many pipeline projects over the past 10 years. The resulting lessons learned from these and other projects have refined the way we approach the design of high temperature, critical service long-distance pipelines.

Pentair and Rilco Sulphur Pipeline Project Experience

- Middle East 12" x 34,500 m Sulphur Pipeline (2008), 6" Sulphur Pipeline (2011)
- North America 4" x 1,630 m Sulphur Pipeline (2012), 6" Sulphur Pipeline (2017)

Rilco Manufacturing has developed a unique design for a high temperature insulated anchor support. The following technical discussion outlines the thermal and structural aspects and innovations required to accomplish this anchor design.

Introduction

Typical high temperature pipe systems require anchor points along the pipeline in order to manage pipe movement due to thermal growth. These anchor points are determined from pipe stress analysis by the pipeline designer. Anchor Support design starts with early pipeline decisions:

a. Anchor/expansion loop spacing - this drives axial forces in the pipe stress analysis, which ultimately determines the size/mass of the anchor design.
b. Friction factors and slide plate options.
c. Trade-off between the quantity/cost of anchors vs. quantity/cost of expansion loops.

Often, while these structural elements are considered, the thermal analysis is often overlooked. As design loads are considered, the design of the anchors mechanical frame and thermal losses throughout the frame must be identified as key considerations to the overall project development.

Why does anchor heat loss matter? For temperature critical fluids (e.g., Sulphur), there are two critical scenarios:

a. A stagnant flow condition (plugging/freezing), preventing the resumption of pumping operations.
b. Re-melt (pipe rupture potential from overpressure).

The ideal objective for a "thermally isolated" anchor design is to provide an anchor support with no net increase in heat loss vs. the heat loss of the adjacent pipe insulation. This is typically stated as "A Homogenous Thermal Profile" in specifications. While this goal is a difficult task to accomplish, Rilco Manufacturing has introduced some new concepts towards that end with the "HE-SAS" High Efficiency-Sulphur Anchoring System.

Fig. 1: Heat Loss Objective

Insulated Pipe Support Anchor Design

Insulated Pipe support anchors for Sulphur must satisfy three critical functions:

1. Restrain piping design loads, including axial loads imparted on the support by the piping system while satisfying code requirements such as ASME B31.3.
2. Minimize thermal losses by eliminating metal-to-metal contact between the pipe and the supporting structure.
3. The support must not impair the installation or functioning of the Electric Heat-Tracing and Fibre Optic Temperature monitoring systems.

Unlike supports that are welded or clamped directly to the carrier pipe, insulated pipe supports integrate an insulation component capable of restraining piping loads. For high temperature applications, insulated pipe supports are usually a combination of high-density load bearing insulation with structural properties and low-density piping insulation. The lower density piping insulation materials such as calcium silicate, perlite, mineral wool, foamglas and aerogel blankets typically do not have the mechanical strength necessary for high-load pipe support applications. While much of the volume of high temperature insulated pipe supports may be low-density insulation, high density, high strength "inserts" must be placed within the design to transfer piping loads to the steel cradle of the support.

Traditional Insulated Pipe Support Anchor Design

To restrain vertical and lateral loads, high strength inserts made from structural grade refractory materials are placed between the inner bore of the support cradle and the outer bore of the pipe. Inserts are also placed in the upper section of the support to transfer clamping loads between the pipe and the support cradle. A design challenge with insulated anchor supports is how to restrain high axial loads through the support insulation. To achieve this requirement, radial pipe lugs are field welded to the pipe. Axial piping loads are transferred through these pipe lugs via a section of high density, high strength insulation, which are in-turn supported by a radial lug welded to the inner cradle of the support cradle. Due to its very low tensile strength characteristics, the high-density insulation must remain in compression between the pipe lug and the housing lug.

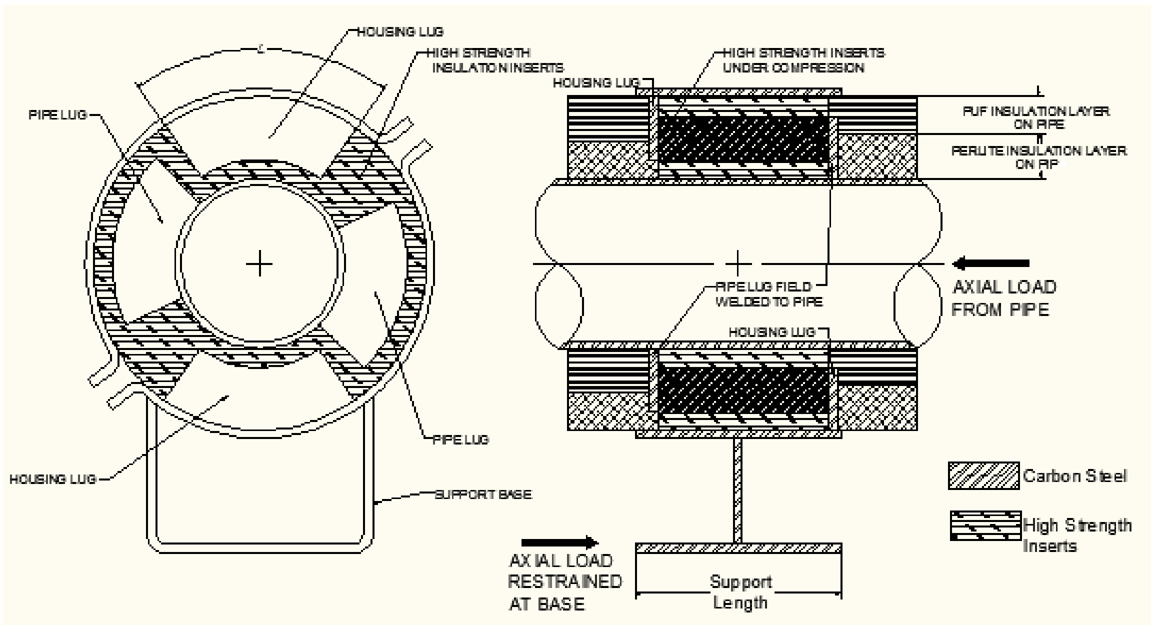


Fig. 2: Traditional Insulated Pipe Support Anchor Design

Traditional insulated supports are typically supplied with four (4) pipe lugs that are field welded to the pipe. Each end of the anchor requires two of these lugs, theoretically evenly restraining the axial pipe load. Note in Fig. 2 that these lugs do not fully encircle the pipe, but cover between 50 degrees and 85 degrees around the pipe depending on the pipe size and insulation combination. While eliminating metal-to-metal contact, this configuration has significant design limitations, especially when attempting to balance the load carrying capacity with efficient heat loss properties. The penetration of the housing and piping lugs into the insulation compromise the thermal efficiency of the support insulation by creating a path of high thermally conductive steel near the outer surface of the insulation (for the pipe lug) and the outer surface of the pipe (for the housing lug) as shown in Fig. 3.

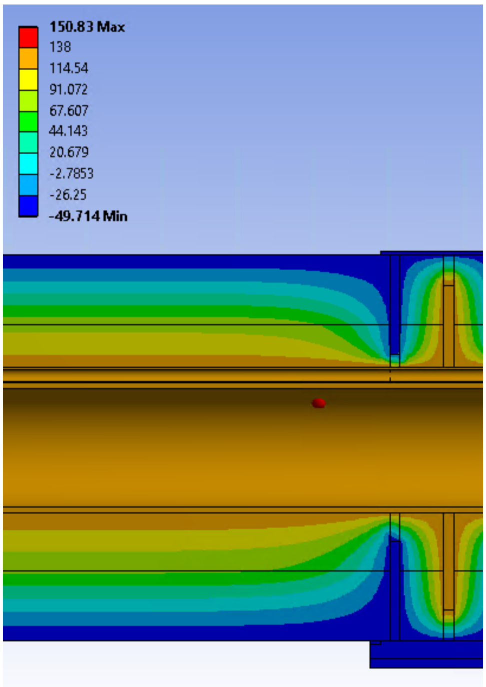


Fig. 3: FEA Model of the Lug Conductive Heat Paths

The high density inserts located between the pipe and housing lugs, utilized to restrain axial loads, are in direct contact with the pipe which creates additional thermal losses in comparison to the Perlite/PUF insulation. Additionally, the narrow cross section of the radial pipe lug is limited in its ability to restrain axial pipe loads without creating excessive localized stresses in the pipe wall. Finally, on Sulphur pipelines, heat tracing tubes and temperature monitoring cables are positioned on the top of the pipe. With traditional radial pipe lugs, the lug at the top requires holes for the tubes and the cable to pass through the pipe lug, complicating the field installation. Additionally, given the location of the pipe lugs, field welding must be performed while in close proximity to the tubes and cable.

Fig. 4: Traditional Insulated Pipe Anchor Support

Insulating materials discussed throughout this paper (listed in descending “k” value order):

Table 1 Pipe and Anchor Insulating Materials

Insulating Material	Typical “k” Value BTU-in/hr-ft²-°F	Typical “k” Value W/m-K
Aerogel Type	0.15	0.022
Urethane Foam	0.17	0.025
Mineral Wool	0.25	0.036
Perlite	0.48	0.069
Structural Insulating Material	Typical “k” Value BTU-in/hr-ft²-°F	Typical “k” Value W/m-K
Marinite P	1.18	0.170
Timtherm 860	1.63	0.235
Marinite C85	2.15	0.310

STS Skin-effect Explained

An STS Skin-Effect Trace-Heating system consists of a basic heating element (i.e. heat tube) that is welded to the carrier pipe (See Fig. 5). The weld is “non-structural” and strictly required as a heat transfer vehicle to the carrier pipe. Installed in the heat tube is a custom insulated and manufactured, high temperature, nickel-plated copper wire that serves as an electrical power carrier, and to a lesser extent, a heating element.

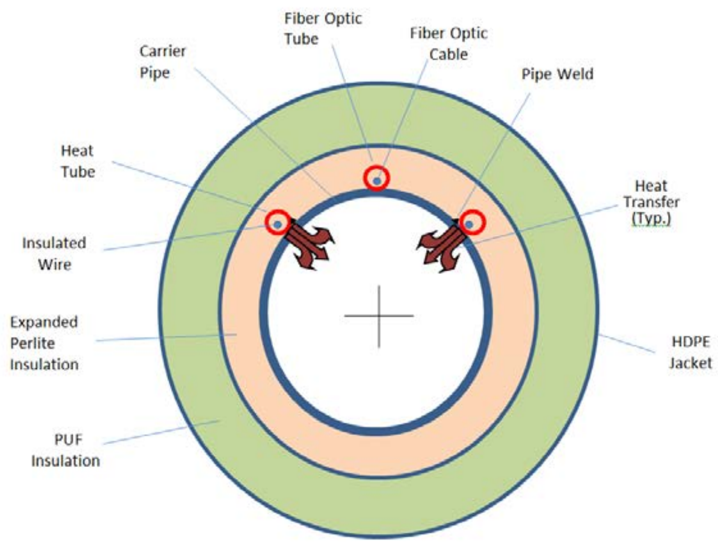


Fig. 5: Cross Section for Multi-Tube Welded System

This conductor is terminated at the far end or centre feed of a carrier pipe and the system current passes through the conductor, and then returns back through the heat tube. Since the insulated copper wire is located inside a hollow ferromagnetic steel tube, the inductive interaction between the “go” and “return” currents causes the current in the carbon steel pipe to concentrate at its inner surface. The resistance to the current flow in the heat tube produces heat, which is then conducted into the carrier pipe via the weld. STS heat tubes typically apply a constant wattage input of 25 to 65 watts per meter.

Fibre Optic Distributed Temperature Sensing (DTS)

Pentair's experience gained from managing the design concept to commissioning of many recently installed Sulphur pipeline projects offers significant insight into the future for Sulphur transport pipelines. Innovative technologies available today are applicable for these types of pipelines include fibre optic based Distributed Temperature Sensing (DTS) systems. This technology offers superior capabilities to the pipeline in monitoring real time temperature data, resulting in more reliable, secure and safe pipeline operations.

For distributed temperature measurement, a pulsed laser is coupled to an optical fibre through a directional coupler. Light is backscattered as the pulse propagates through the fibre's core owing to changes in density and composition as well as molecular and bulk vibrations. In a homogeneous fibre, the intensity of the sampled backscattered light decays exponentially with time. Because the velocity of light propagation in the optical fibre is well known, the distance can be calculated from the deterministic collection time of the backscattered light. Thus, the temperature and distance can be resolved simultaneously.

The real benefit of a fibre optic based measurement system is in the customized graphical user interface (GUI). The purpose of this type of diagnostic tool is to develop graphics which put pertinent and relevant information into the hands of the End User, so that they can make real time operational (and/or maintenance) decisions on the pipeline. These include:

- Provides a continual axial measurement method (within 1 meter) and can identify hot/cold spots (within 1°C).
- Profiles the entire length of the pipeline.
- Identifies localized problems, e.g. pipe supports, anchors, field joints, and insulation breaches.

As shown in figure 6 below, this is an example of what can be "seen" on the fibre optic GUI by zooming in on the support's location. The temperature drop shown indicates that the heat loss is much larger at the anchor point compared to the adjacent insulation during a non-flowing condition.

Fig. 6: Fibre Optic Temperature Readings at the Anchor Location

The fibre optic system can monitor daily temperature fluctuations at each anchor point. In the figure 7 example, the temperature drop is 20°C at the anchor before pumping is performed.

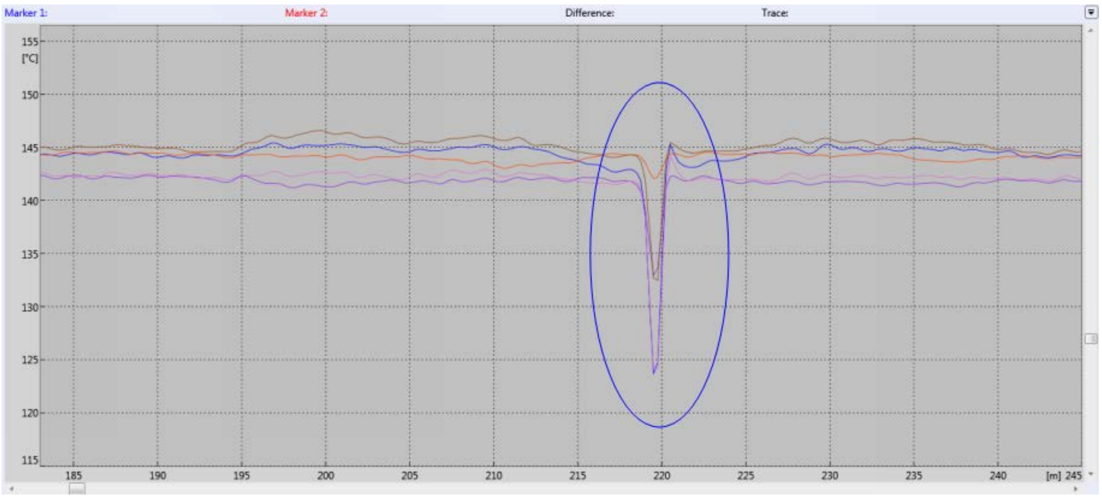


Fig. 7: Daily Temperature Change at Anchor

Lessons Learned

1. The most important observation from Fibre Optic monitoring data is that the temperature inside the anchors (the pipe wall temperature) during heat up, lags behind the pipeline temperature as it rises. Figure 8 represents the actual GUI screen trace data for the heat-up of a sulphur pipeline over a period of several days, which indicates the lower temperatures near the anchor support locations.

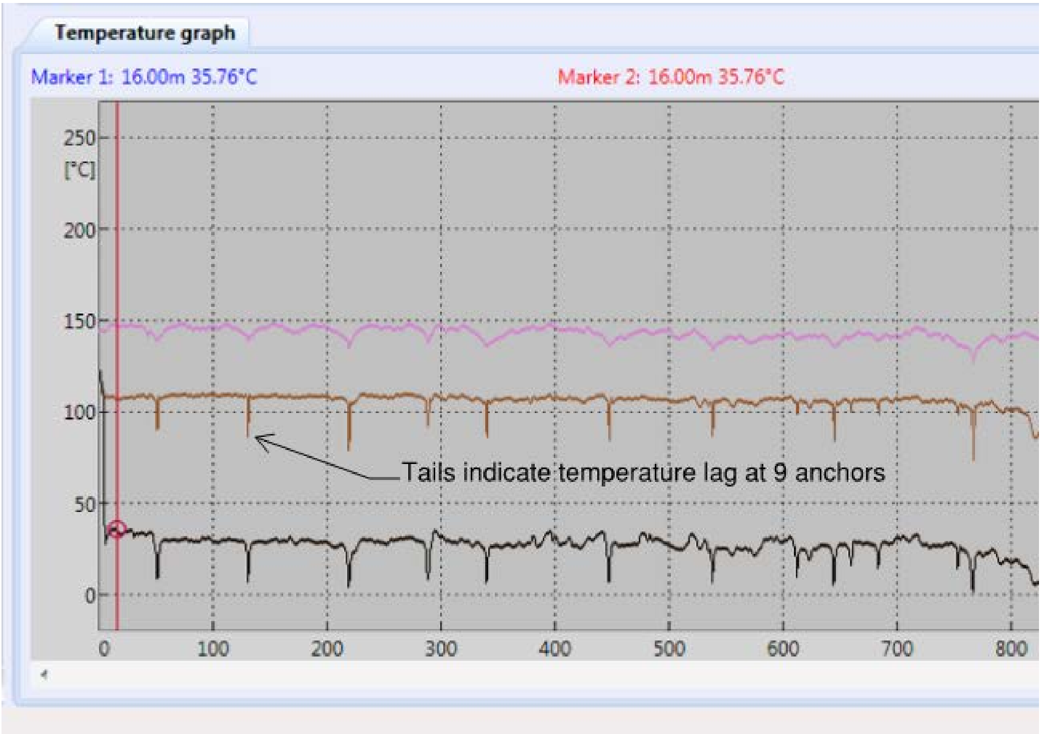


Fig. 8: Fibre Optic Temperature of the Pipeline During Heat-Up

This anchor performance is also found when the system cools down, i.e. the anchor temperature falls (leads) ahead of the pipeline temperature.

The thermal performance of the anchor is critical to any Sulphur pipeline. Significant lag in temperature could lead to plugged zones between anchors, which creates overpressure situations as the Sulphur volume expands (+9% due to the Sulphur phase change).

2. Traditional anchor supports have multiple plates, inserts, and pieces, which complicates installation. A common error is that some pieces may likely be installed incorrectly or completely missed during construction. This can leave openings between plates, which results in significant heat losses leading to localized freezing of the sulphur.

Fig. 9: Thrust Plates and Pipe Lugs

HE-SAS Insulated Pipe Support Anchor Design

Within the past decade, aerogel based blanket insulation specifications have steadily increased for pipeline projects, which also increases the requirement for aerogel based insulated pipe supports. A key feature of the aerogel insulation is that this requires a much thinner (50-60% less) thickness compared to conventionally insulated systems. Traditional insulated supports rely on a section of high strength insert material to be compressed between the housing lug and the pipe lug. This method is problematic with aerogel based pipe supports given the reduced cross section of the insulation, which significantly reduces the load carrying capacity of the support. In response to this design issue, Rilco developed an insulated pipe anchor, which eliminates the radial pipe lug utilized in traditional insulated pipe support anchor designs, replacing it with a single H shaped "post" design on the bottom of the pipe. This design takes advantage of the space below the cradle of the support and has several key design advantages over traditional designs:

- Eliminates the need for high strength inserts, necessary to restrain axial loads in direct contact with the pipe, thus improving the overall thermal efficiency of the support.
- The "H" shaped axial plug lug provides a reduction in the overall cross section of the component compared to a traditional radial lug welded to the pipe.
- The geometry of the "H" shaped axial pipe lug is inherently better suited to resist axial loads by possessing a larger section modulus compared to a flat radial pipe lug.
- Both the pipe lug and the high strength inserts are separated from the outer steel components with high performance insulation, improving the thermal efficiency of the support.

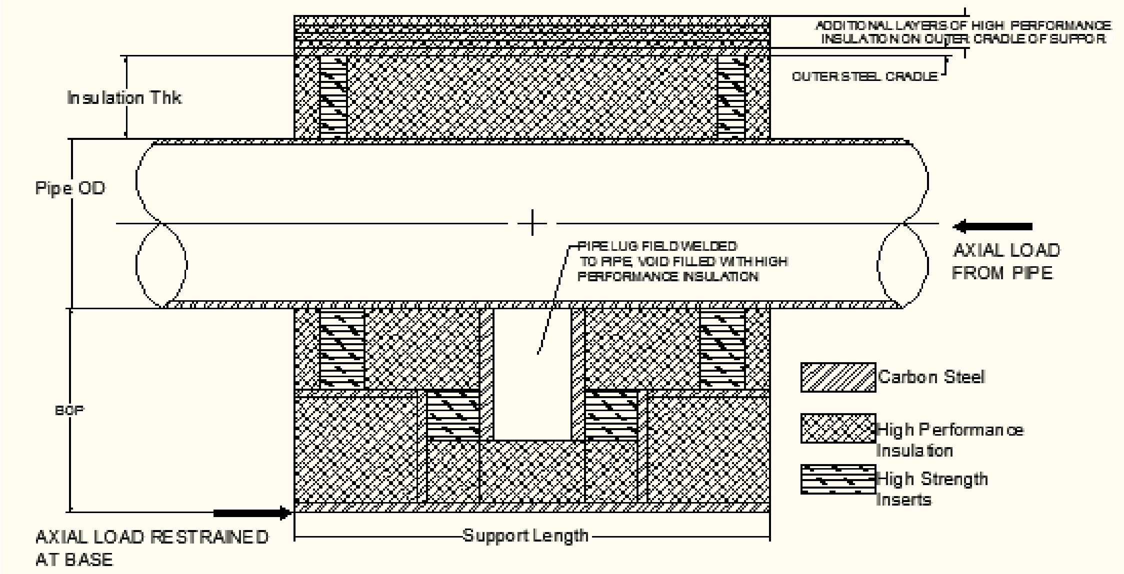


Fig. 10: HE-SAS Insulated Pipe Support Anchor Design

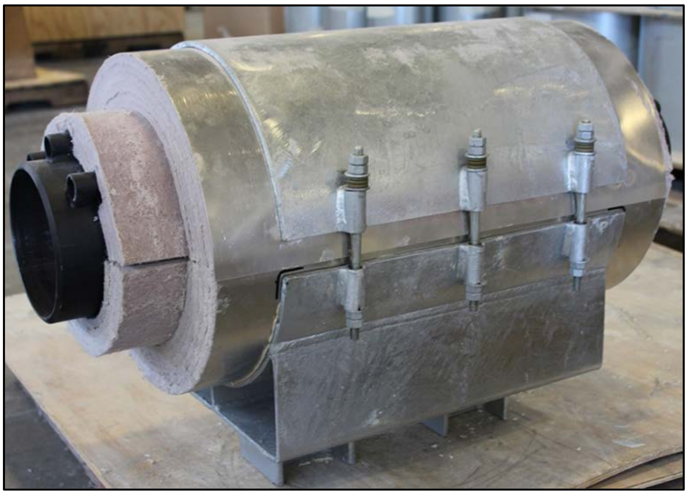


Fig 11: HE-SAS Pipe Anchor

Axial Pipe Lug Design – Comparison of Localized Stresses in the Pipe Wall & Proximity to the Heat Trace Tubes

Figure 12 illustrates a radial pipe lug on a 6” pipe with a 22.2 kN axial load applied to the dark blue area on the lug. Note that this model assumes that the axial load is evenly split between the upper and lower lugs. The model stress results in figure 12 indicate the maximum stress over typical allowable stress limits.

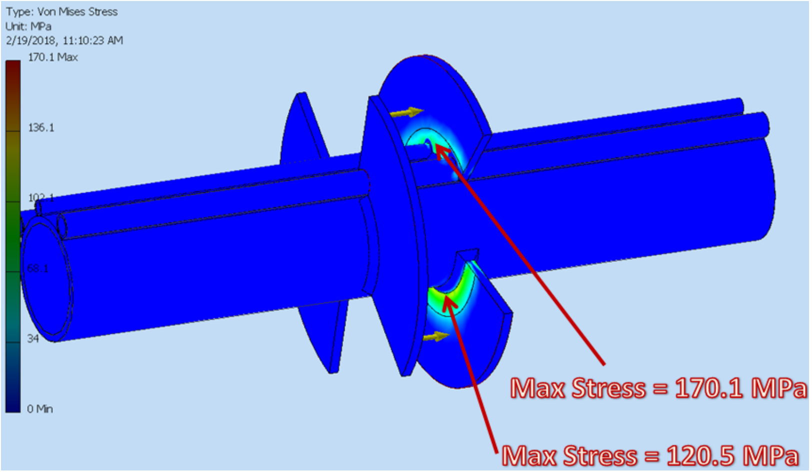


Fig. 12: Traditional Insulated Support Radial Pipe Lug **Stress Results**

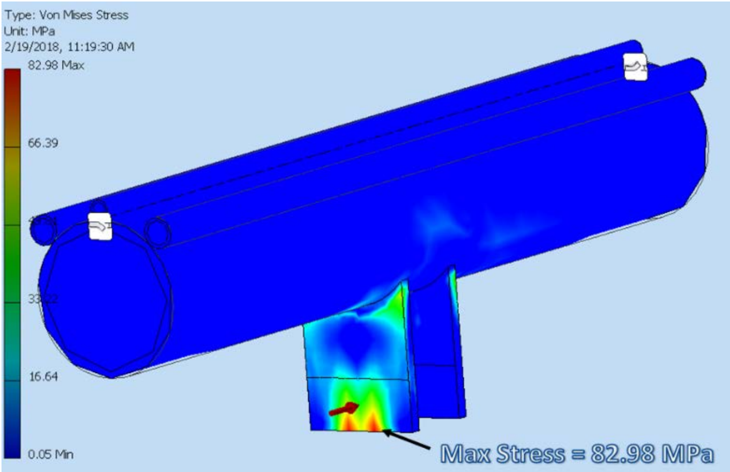


Fig. 13: HE-SAS Insulated Pipe Anchor Stress Results

Table 2 Summary of Localized Stress Results - Traditional Insulated Anchor vs. HE-SAS Anchor

Support Type	Pipe Size & Schedule	Total Insulation Thickness (mm)	Axial Piping Load (kN)	Axial Piping Load (lbf)	Internal Design Pressure (bar)	Top Lug Maximum Calculated Stress (Mpa)	Bottom Lug Maximum Calculated Stress (Mpa)	Stress < 137.8 MPa per ASME B31.3
Traditional Insulated Anchor	6" Schedule 40	167	22.2	4991	14	170.1	120.5	No
HE-SAS Anchor						N/A	82.98	Yes

In comparison, the HE-SAS Insulated Pipe Anchor, with the same 22.2 kN axial load applied at the bottom portion of the lug creates a stress significantly lower than the flat radial design of a traditional insulated anchor. By utilizing the space between the cradle and the base plate, the pipe lug for the HE-SAS Anchor design provides increased flexibility and design robustness compared to a flat radial pipe lug with broader design safety margins. Surge, slug, seismic, upset and other occasional or unanticipated piping loads can also be better accommodated using an "H" or box shaped lug than a flat circular plate. This design also simplifies the installation requirements by keeping the pipe lug away from the heat tracing tubes and FO temperature monitoring cable. As shown in Figure 14, one of the pipe lugs for traditional insulated pipe supports must be fabricated to fit around the two heat tracing tubes and one fibre optic monitoring cable. This can be a problematic if the tubes are not properly positioned on the carrier pipe. Furthermore, this type of lug requires welding within the narrow spaces between the tubes. The HE-SAS Anchor design eliminates this problem by positioning the lug on the bottom of the pipe, on the complete opposite side of the heat tracing tubes.

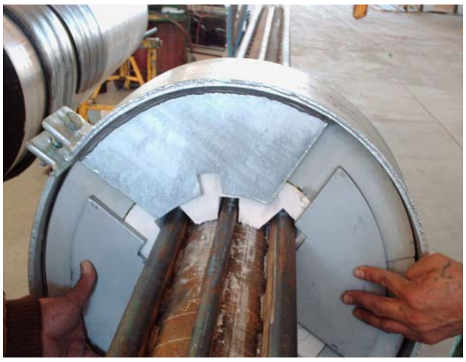
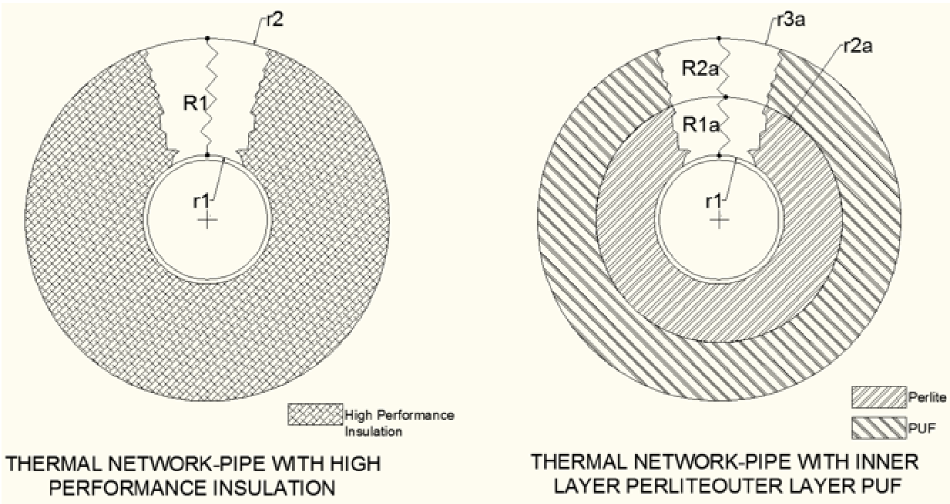


Fig. 14: Pipe Lug on a Traditional Insulated Pipe Anchor
(Note the clash between the slots in the lug and the location of the tubes)

Axial Pipe Lug Design Thermal Efficiency Comparison

A key feature of the HE-SAS Pipe Anchor is the use of high performance aerogel based insulation in place of conventional insulation materials to compensate for the high-density inserts and the steel housing and pipe lug penetrations. By substituting aerogel-based insulation, you can realize a dramatic increase in thermal resistance compared to Perlite + PUF insulation materials for the non-load bearing components of the support.



Total thermal resistance Comparision, 6" pipe, 167mm of High Performance Aerogel / Insulation versus 91mm of Perlite + 76mm of PUF

$$R1 := \frac{\ln\left(\frac{r2}{r1}\right)}{.022 \cdot \frac{watt}{m \cdot K}} \qquad R1 = 49.71\ \frac{K \cdot m}{watt}$$

Total thermal resistance, high performance Aerogel insulaiton

Thermal resistance, Perlite

$$R1a := \frac{\ln\left(\frac{r2a}{r1}\right)}{.0689 \cdot \frac{watt}{m \cdot K}} \qquad R1a = 9.34\ \frac{K \cdot m}{watt}$$

Thermal resistance, PUF

$$R2a := \frac{\ln\left(\frac{r3a}{r2a}\right)}{.025 \cdot \frac{watt}{m \cdot K}} \qquad R2a = 18\ \frac{K \cdot m}{watt}$$

$$Rtotal := R1a + R2a \qquad Rtotal = 27.34\ \frac{K \cdot m}{watt}$$

Total thermal resistance, Perlite + PUF

$$\frac{R1}{Rtotal} - 1 = 81.81\%$$

Percentage Increase in thermal resistance by substituting Aerogel based high performance insulation

Fig. 15: Thermal Model and Comparison

Available in blanket form, this insulation is typically cut to fit intricate portions of the support, creating additional insulating value to spaces and voids that would normally be left vacant. Additional layers of this blanket insulation can be added to the outer cradle of the support to help maintain the heat loss of the piping insulation system.

Another key element is the configuration of the high strength inserts within the support. While technically insulation, the high density inserts are much more thermally conductive than the native Perlite/PUF insulation. High-density inserts must be used between the pipe and the cradle to restrain vertical and lateral loads, but a significant heat loss can also be reduced by moving these high strength axial load-restraining inserts within the base of the support and away from the pipe.

Traditional insulated pipe anchor steel housing lug insulation penetrations are eliminated by moving the support structure for the high-density insert into the base of the support, which stops a major heat loss path. These design elements enable the HE-SAS Anchor to significantly outperform traditional insulated pipe anchors.

The following figures compare heat loss results between a HE-SAS Anchor and a traditional insulated pipe anchor. Both models use the following conditions:

- Ambient temperature: -3˚C
- Wind speed: 18m/sec
- Emissivity: 0.4
- Film coefficient: 28 watts/m^2 *K (applied to outer surfaces)
- Sulphur temperature: 140°C
- Power applied to each heat-traced tube: 22.2 watts/meter

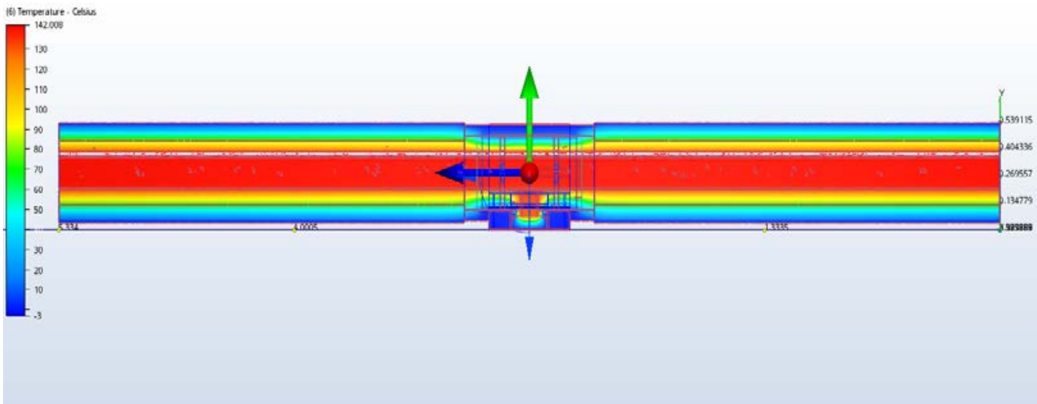


Fig. 16: Cross Section of Thermal Results for HE-SAS Pipe Anchor in Centre

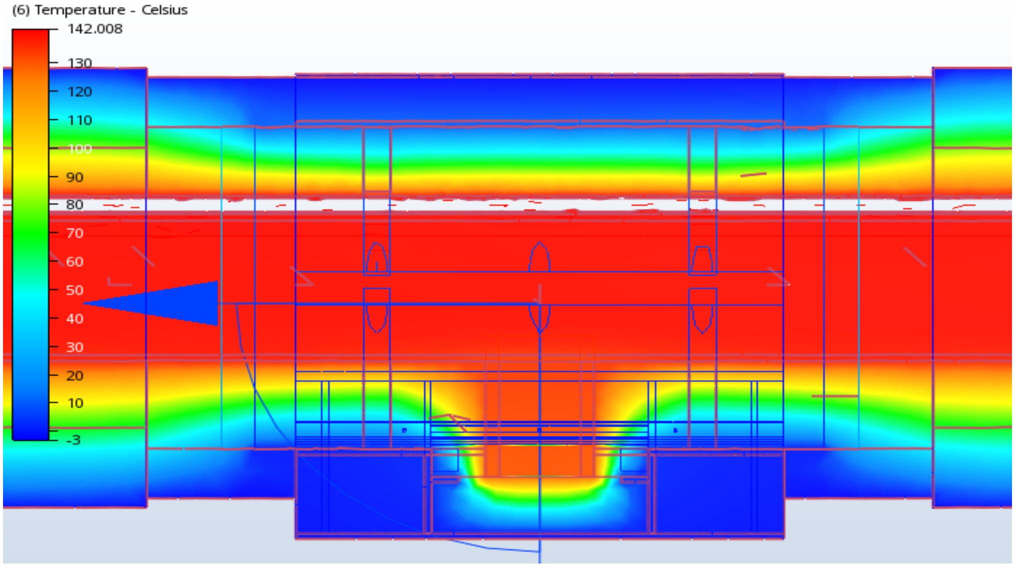


Fig. 17: Cross Section of Thermal Results for HE-SAS Pipe Anchor with Transition to Perlite/PUF Insulation (Note the Temperature Profile Transition from the Support to the Adjacent Insulation)

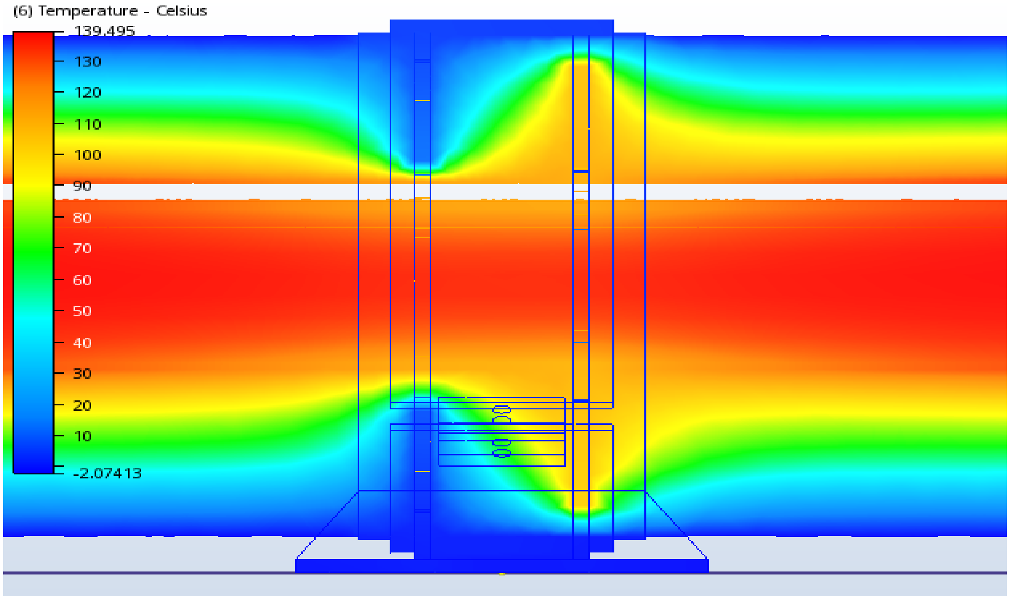


Fig. 18: Cross Section of Thermal Results for a Traditional Insulated Pipe Anchor with Transition to Perlite/PUF Insulation.

Note in Fig. 18, the severe temperature transition between the piping insulation to the blue (or cold) penetration into the insulation on the left side of the support then back to a reddish orange (or hot) penetration on the right side of the support. The blue penetration is the housing lug of the support transmitting negative heat flow into the interior of the support insulation and the reddish orange penetration is transmitting positive heat flow to the exterior of the insulation, which both negatively impact the thermal performance of the support. Compare this to the temperature profile in Fig. 17, illustrating the temperature profile of the HE-SAS support. The overall temperature profile is much closer to that of the piping insulation, with a single, narrow penetration around the pipe lug at the bottom of the support, providing for a better overall insulating value.

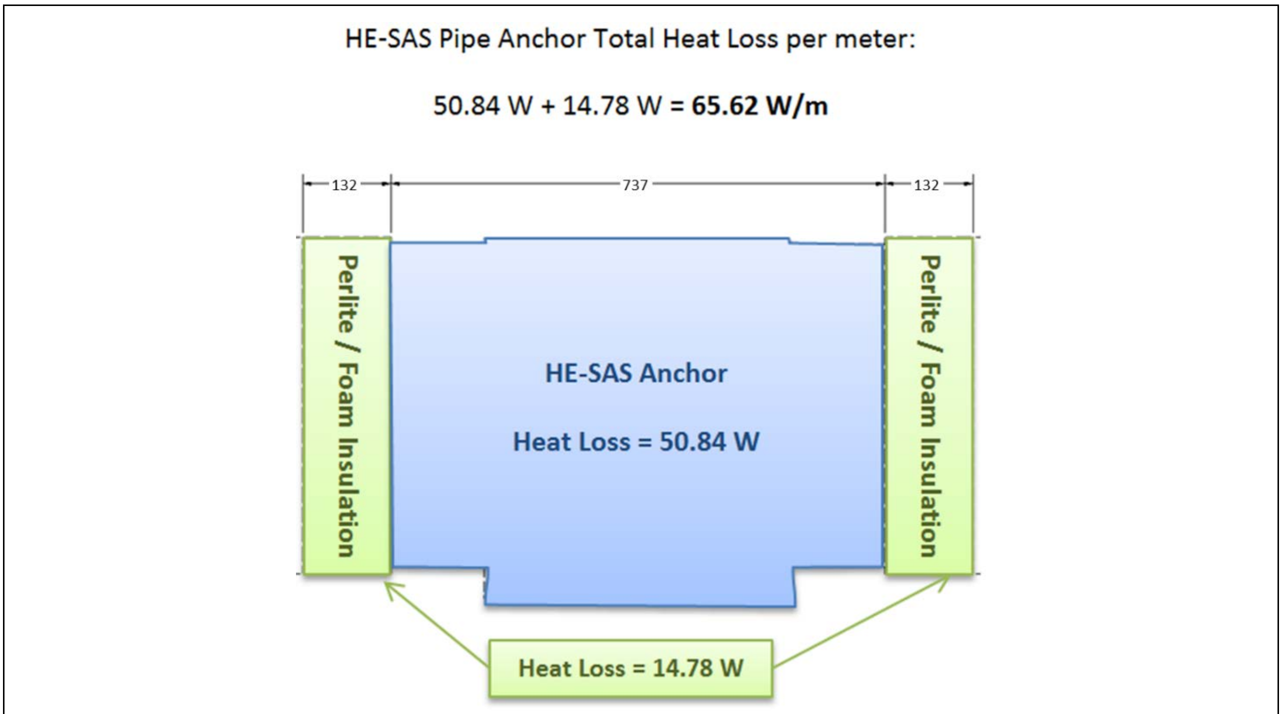


Fig. 19: Summary of Heat Loss of the HE-SAS Anchor Over One Meter of Pipe

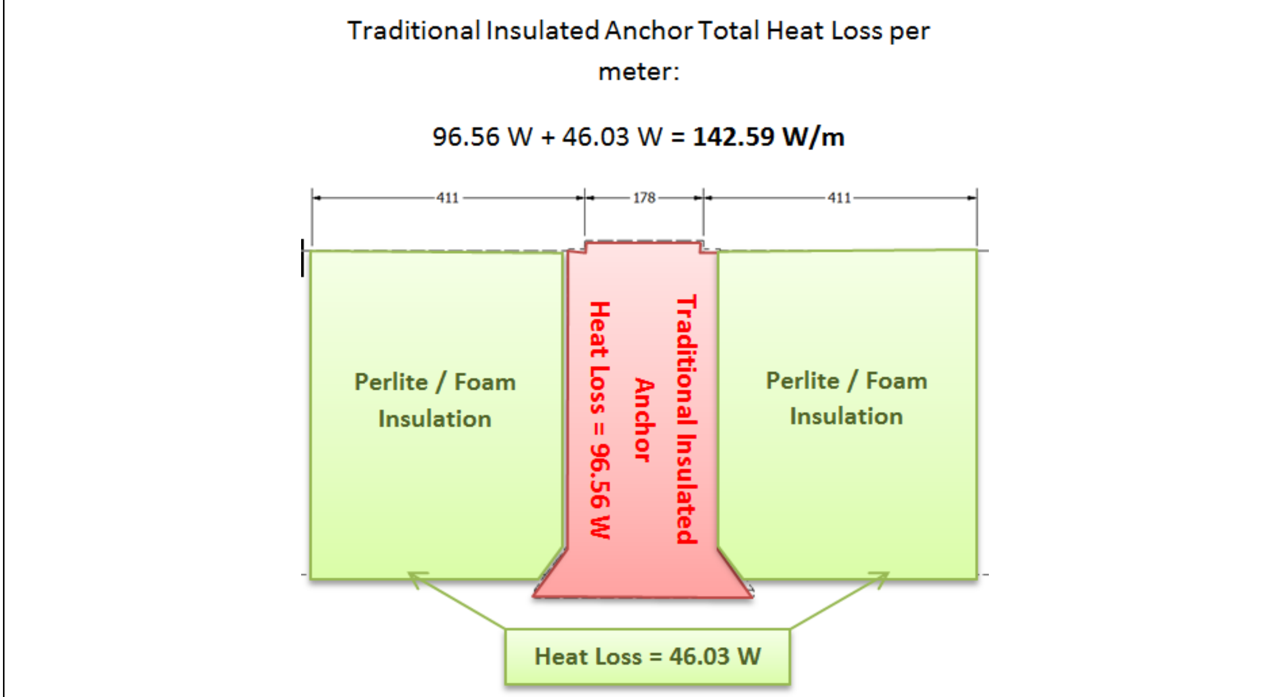


Fig. 20: Summary of Heat Loss of a Traditional Insulated Pipe Anchor Over One Meter of Pipe

Figures 19 and 20 compare the total heat loss values between the HE-SAS anchor and the traditional insulated anchor over a one-meter section of pipe. This measurement method serves as a convenient comparison between the heat loss values per meter of the piping insulation (Perlite and PUF) versus a one-meter section of pipe including the pipe anchor. Although the HE-SAS anchor is longer in length, it significantly outperforms the traditional insulated pipe anchor.

A Note About the FEA Models:

The FEA software used for this research are - Autodesk Simulation 360 CFD (Rilco) and ANSYS 15 (Pentair).

Future Developments:

1. Pentair has developed a fibre optic software program AUTO-Melt™ for Sulphur Pipelines, explained in reference 1 on this paper. This software tool will allow operators to immediately identify problem areas in the pipeline and make sound adjustment decisions based on temperature data.
2. Pentair is currently evaluating temperature data for a Sulphur pipeline in Canada where these new support designs are not yet filled with Sulphur.

Conclusions

The main topics of this paper are summarized as follows:

1. Continuous improvement in the design of pipe anchors is necessary for critical service pipelines. It is very important to review the anchor support mechanical design and heat loss very early in the design process (FEED & stress analysis). This design process would include early FEA thermal modelling efforts.
2. The benefit of Fiber Optic monitoring systems it that they allow you to “see” inside supports and anchors.
3. Thermal efficiency is improved by minimizing the amount of high strength materials and maximizing the use of the lowest k-value insulation. This design when combined with the repositioning of the structural elements have a positive impact on the pipeline performance.
4. The Pyrowrap “HE-SAS” Sulphur Anchoring System is a step in the right direction towards a more effective thermal and mechanical anchoring of sulphur pipelines. Rilco is currently designing these supports for a full range of modelled pipe sizes from 6” to 12” for Sulphur service.

References

1. “Automated Re-Melt Program for Sulphur Pipelines – A Revolutionary Advancement in Safety with State of the Art Bundled Technologies” (Franco Chakkalakal, Mike Allenspach, Kent Kalar, Hassan Armaneh) This paper was previously presented at SULPHUR 2016 in London, UK.

Acknowledgements

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