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Investigation Tactics for Prevention of Floating Roof Rim Seal Failures

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Introduction

Minimizing costly disruptions caused by floating roof issues is critical for owner/operators looking to maximize tank performance and improve the operational reliability of their aboveground storage tanks. Of the many components impacting the performance of a floating roof, rim seals are often exposed to demanding environmental conditions as well as demanding operational envelopes. Given the challenges, rim seals are required to maintain consistent and problem-free performance. Tank owners expect rim seals to operate flawlessly throughout the maintenance cycle, and rim seals are frequently monitored and inspected for compliance with local and national regulations. Rim seals found to be out of compliance must be repaired, which can result in costly impacts on operations and the environment. It is important to highlight that the risk associated with rim seal failures is not just about downtime and operational costs; the primary purpose of rim seals and other emissions control products is to protect the environment by containing and preserving the product stored.

Therefore, the failure of a floating roof rim seal is a critical problem in both midstream and downstream sectors. A calculated and thought-out investigation into aboveground storage tank floating roof rim seal failures is required to provide usable and relevant data to support sound risk mitigation decisions. Incorrect assumptions and conclusions can result in additional unexpected and expensive downtime. It is important to understand the key characteristics of seal failures and their potential causes. In this article, a thoughtful and logical approach to diagnosing rim seal failure modes, as well as case study examples, is provided. Tank owners, contractors, engineers, and inspectors will find this information a useful addition to their failure inspection analysis toolbox.

Rim Seal Failure Modes

The United States government defines the type of rim seals to be used in specific aboveground floating roof storage tanks through the Code of Federal Regulations 40 CFR Part 60, Subpart Kb in the current edition [1]. Rim seals are used to provide a barrier between the floating roof and the tank shell with the purpose of controlling emissions from the stored product. Rim seal designs differ in physical construction and how they perform the task of emission control, with certain floating roofs requiring specific designs. As such, external and internal floating roof tanks utilize different requirements for rim seals. Even though requirements differ, all rim seals for aboveground floating roof storage tanks are subjected to numerous physical and environmental forces. The variability in the design of rim seals requires a broad examination of factors that impact performance and may cause a rim seal failure.

Specifically, the modes of rim seal failure can be broken down into degradation, tolerancing, adhesion, and external forces. These failure modes can apply to certain designs of rim seals or can be all-encompassing. This article will break down these failure modes and how they are applied to floating roof rim seals.

Degradation: Polymers

Several rim seal designs include rubber or polymer components that provide a barrier between the volatile product and the atmosphere to control emissions. These polymers are typically used as wedge wiper seals (in primary or secondary form) or steel secondary seals with polymer extrusions acting as wiper tips.

In the case of wedge wiper seals, the entire seal is comprised of a flexible polymer. This flexible seal is mounted on the floating roof and extends to the tank shell. The polymer is typically formed into a wedge shape where the thicker portion of the polymer is attached to the floating roof, and the thinner portion of the wedge is pressed against the tank wall. The wedge wiper is sized larger than the rim space so that it ensures constant contact. In this manner, the wedge must bend to form an arc. With this design, the wedge wiper seal is subjected to bending forces as it is required to flip in different directions during operation when changing from a fill to a drain cycle.

In the case of steel secondary seals with polymer extrusions acting as a wiper tip, the polymer is supported by a steel compression plate against the tank shell. The polymer extrusion is fastened to the steel plates, typically through bolted hardware, and is pressed against the tank wall by the steel compression plates. The steel plates are secured to the floating roof and utilize a manufactured bend that forces the polymer extrusion to be pressed against the tank shell. As the polymer extrusions are merely forced against the tank shell, there is no additional bending or other forces applied to this polymer besides compression.

Understanding how these polymers work and the forces that they are subjected to can help one determine the failure modes that may occur through degradation.

Polymer degradation is caused by exposure to light, oxygen (specifically ozone), and/or heat, which can impact the polymer's structure and cause changes to its mechanical properties. When exposed to light, ozone, and/or heat, the polymer can undergo chain hardening (embrittlement) or chain scission (softening). In application, having the properties of the polymer either soften or become brittle creates challenges that can lead to failure.

Specifically in the aboveground floating roof storage market, polymers are typically prone to chain hardening. Whether the polymer is installed on an internal or external floating roof tank, it will be exposed to varying levels of light, ozone, and heat, which

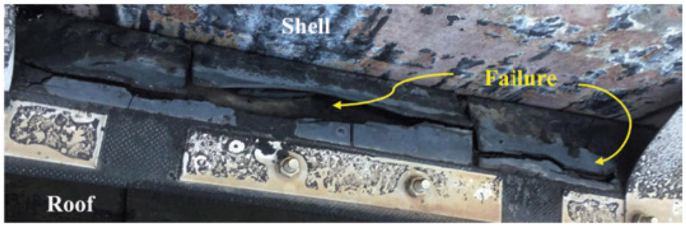

Figure 1. Chain hardening failure of polymer under bending forces.

are unavoidable throughout the life of the product. Wedge wiper polymers and metallic secondary seal polymers will react differently to chain hardening and show different failure modes.

Chain hardening causes the polymer to stiffen and become brittle. Light, ozone, and/or heat cause free radicals to interact with the polymer to create crosslinks between the polymer chains. Joining the polymer chains together reduces the flexibility and makes the polymer increasingly stiff and brittle. When wedge wipers are subjected to consistent and often cyclic bending forces, stiffening can result in brittle failure that appears perpendicular to the direction of stress. In this case, it appears parallel to the tank shell (**Figure 1**).

Metal secondary seal polymers also experience chain hardening and stiffen after extended exposure to light, ozone, and heat. However, these materials experience mostly compression forces and do not require bending to operate. The chain hardening, therefore, may not result in a catastrophic failure such as brittle failure in wedge wipers, but it may cause gaps in the sealing area as the stiffened polymer lacks resiliency to conform to irregularities in the shell wall. If the metallic secondary seal polymer is observed to be very stiff, it could be an indication of chain hardening.

Chemical Degradation and Compatibility: Emission Control Fabrics

Chemical degradation can also occur in other soft materials, such as emissions control fabrics used on mechanical shoe seals. It is important that the seal manufacturer and tank owner are knowledgeable about the products that may be stored in the tank throughout its service life. Selecting emissions control fabrics that can withstand chemical interaction with the product stored is necessary to ensure extended reliable performance.

It should also be noted that even chemically inert materials can be attacked chemically, if there are other non-inert materials used in the construction of the fabric. An example of this is Teflon fabric with a fiberglass scrim. The fiberglass is used to provide resistance to tearing and provide strength to the Teflon film, which has very little structural strength. In certain environments, chemicals can interact with the fiberglass and cause stiffening and brittleness. This stiffening compromises the flexibility of the fabric and can lead to brittle failure of the emissions control fabric. Hydrogen Sulfide (H_2S) is a common compound found in stored fluids in the aboveground floating roof storage market. Extremely high concentrations of this compound can adversely affect inert Teflon fabric, particularly if it contains a fiberglass or another form of scrim, as the fiberglass will react with the H_2S. This presents as a brittle failure in the fabric (**Figures 2** and **3**).

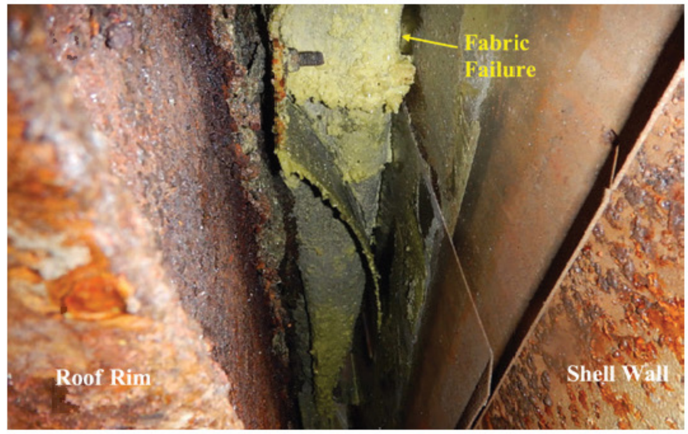

Figure 2. Hydrogen Sulfide (H_2S) buildup on chemically inert Teflon emissions control fabric with fiberglass scrim.

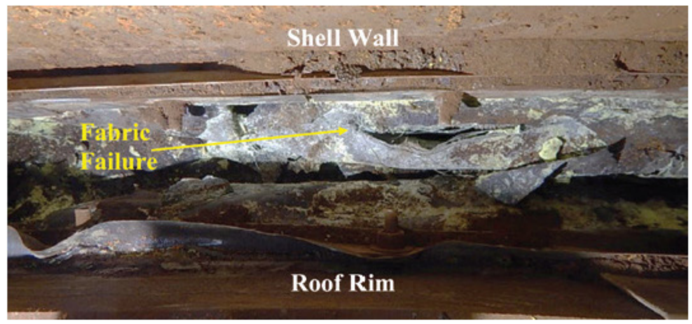

Figure 3. Hydrogen Sulfide (H_2S) causing brittle failure to Teflon fabric with fiberglass scrim.

In addition to considering the chemical compatibility of soft components such as polymers and emissions control fabrics, it's crucial to carefully select metallic components to ensure compatibility with the stored products. Some examples of compounds that can cause concern for both soft and metallic parts are Ethanol, Benzene, H_2S, Methyl Ethyl Ketone (MEK), and even water.

Soft components of rim seal systems typically utilize materials like urethanes, Teflon, nitriles, and polyethylene. Each of these materials has specific resistances to substances and must be assessed strategically based on the product stored.

Additionally, metallic parts must be considered for resistance to stored products. Galvanized carbon steel and 300 series stainless steel are predominantly used in the industry for floating roof rim seals. Each offers specific resistance abilities. Galvanized carbon steel is protected by a thin layer of zinc, but if that layer is impacted, the protection against corrosion or other interactions is greatly reduced. 300 series stainless steels offer better corrosion protection and can withstand most of the products typically stored in aboveground storage tanks. However, corrosion protection varies depending on the series of stainless steel. 301 stainless steel offers the least corrosion protection, while 316 series stainless steel offers the most corrosion protection in that range. 304 stainless steel provides an advantageous balance of corrosion resistance to cost. Analyzing the product stored is essential to ensure the rim seal can survive the harsh conditions created by the product stored.

Figure 4. Overextension of mechanical shoe pivot linkage results in primary seal inversion.

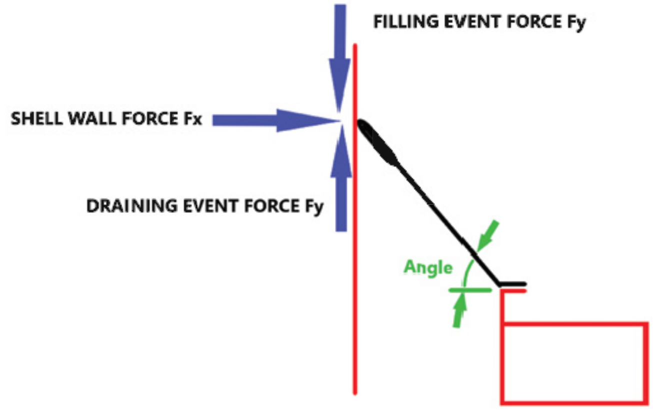

Figure 5. Demonstration of forces applied to metal secondary compression plate seals.

Dimensional Tolerances: Sealing Envelope

All primary and secondary floating roof rim seals are designed and built to operate within a specific rim space tolerance. The rim space is defined as the area between the floating roof and the shell wall. According to American Petroleum Institute (API) Standard 650, the rim seal must be able to seal a rim space envelope that is +/- 4 inches from the nominal or average rim space [2]. For example, if the average distance of the rim space is 8 inches from the floating roof rim to the shell wall, the rim seal must operate in a rim space of 4 inches to 12 inches. This large envelope requires the rim seals to be extremely flexible and resilient. As the rim seal is compressed or condensed to the low end of the tolerance, there is an increased force applied to the seal and shell wall. As the rim seal is extended to the high end of the tolerance, the force applied by the rim seal to the shell wall is lowered.

Mechanical shoe primary rim seals utilize pivot points and arms to create a linkage that extends the shoe plate to press against the shell wall. The extension force is typically applied by springs or formed metal pushers. As the rim space narrows, the linkage collapses, and as the rim space grows, the linkage extends. Primary seals are designed to operate within the +/-4 inch rim space; however, the primary seal can navigate a rim space envelope beyond the designed tolerance.

As the rim space narrows and the primary rim seal compresses beyond the specified minimum tolerance, there reaches a point where the linkage cannot physically collapse any further. In this case, if the primary rim seal must navigate a rim space smaller than the total collapsed profile of the mechanical seal, it can cause binding between the floating roof and shell wall, restricting or stopping movement. This restriction can cause damage to the seal and in the worst case, can result in a sunken floating roof.

Conversely, when the rim space expands and the primary seal extends beyond the maximum tolerance, the pivot and arm linkage may reach a limit where further extension becomes infeasible. When the linkage is overextended, it allows the pivots and arms to flip, causing an inversion. This results in the primary shoe plates extending below the floating roof, rendering the primary seal useless. Typically, the mechanical shoe seal fabric can offer some protection against inversion by limiting extension movement. However, it is possible, especially with primary rim seal pivot systems utilizing a pivot that is centralized in the rim space and those with undersized arms, to invert (**Figure 4**).

Steel secondary seals are also susceptible to tolerances outside the +/- 4-inch rim space envelope. Steel secondary seals use compressive force to hold the polymer extrusion in contact with the shell wall. This force is obtained through an acute bent angle of the steel compression plate. The metallic compression plate then extends from that bent angle towards the shell wall and must be sized to contact the shell wall throughout the entire tolerance range.

As the rim space narrows, the metallic secondary seal compression plate must flex into a more vertical position. If the rim space narrows to a tolerance less than the seal tolerance, this can put added stress on the compression plate that can cause yield strength failures. Additionally, as the metallic compression plate is pushed vertically, it can lessen the compression force of the seal and reduce the ability of the polymer extrusion to contact the shell wall.

As the rim space grows, the steel secondary compression plate will extend to equilibrium, where the compression plate was originally pre-formed at the acute bend angle. As the pre-formed angle approaches, the compression plates provide less force, which results in less supporting force from the shell wall to the secondary seal. If the rim space extends beyond the maximum tolerance of the seal, this lack of force and contact can result in the secondary seal losing enough support force to remain in a vertical condition. The polymer extrusion wiper tip can create enough friction to overcome the vertical support force of the compression plate, which causes a rollover of the secondary seal. This can be seen as the compression plate being formed into a half circle, with the extrusion now extending downward towards the product

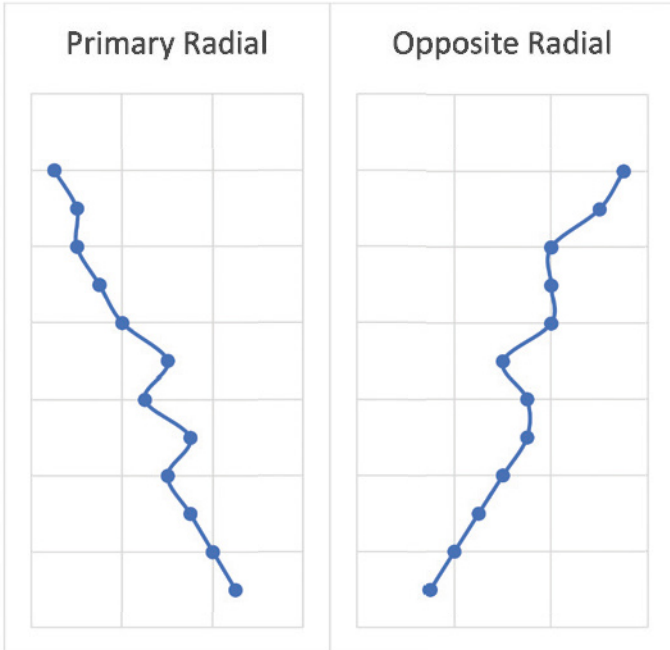

Figure 6. Shell wall verticality divergence across opposite radials.

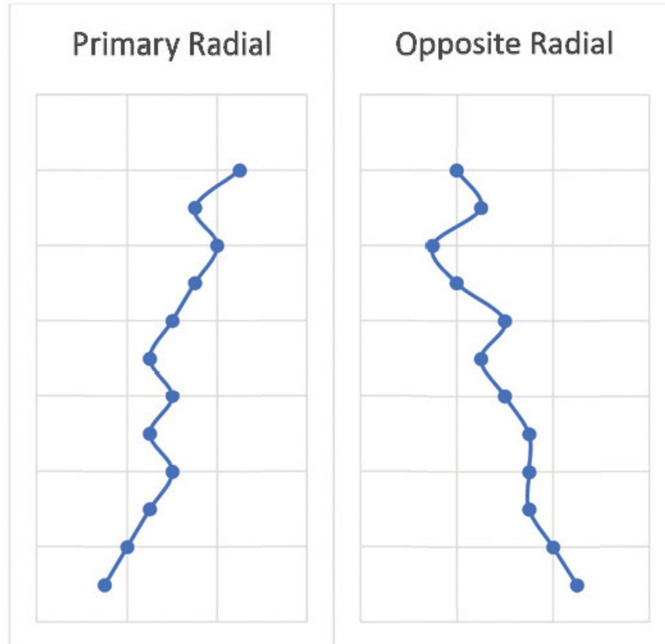

Figure 7. Shell wall verticality convergence across opposite radials.

stored. This failure can propagate and typically requires complete removal and replacement of the affected areas (**Figure 5**).

Dimensional Tolerances: Verticality and Roundness

Understanding how primary and secondary seals behave and potentially fail from tolerance leads us to how or why this happens in aboveground storage tanks. The geometry of the tank shell wall in aboveground storage tanks can be complex. As these tanks are field-built, the tanks are subject to construction variability and imperfections. Additionally, the tanks are subjected to foundation loading and unloading, as well as other environmental factors, which can lead the tanks to have variations in verticality and roundness. The tolerance of the rim seal typically handles the variation, but if the geometry of the shell wall and the rim space allows, the rim seal will be required to navigate a rim space outside the designed seal tolerance.

When performing tank inspections, it is recommended to include laser scanning. This scanning maps the dimensional characteristics of the tank and helps to paint a picture of the structure of the shell wall. However, laser scanning of the shell wall is not the complete story, as rim spaces are needed for comparison at these scanning points to determine what the rim space is and what the rim seal needs to navigate. Data should be taken in multiple locations and spaced with readings 180 degrees apart or directly across from one another on the diameter of the tank. Readings are typically lined up at specific points around the tank and are referred to as radials. These radial readings help the seal manufacturer understand how movement in one section of the tank can impact the seal on the opposite side of the tank.

As the floating roof moves and navigates the rim space, it can move closer to one side of the tank while moving further away from the opposite side. These movements are complex and require the rim seal to navigate many irregularities. These irregularities are expected, and the rim seal is designed to move in an envelope of +/- 4 inches, as per API 650, and in many cases, the movements do not cause failures [2]. If the tank's geometry and the rim space challenge the design envelope for the rim seal, this can lead to tolerance failures, as discussed in the previous section.

Verticality measurements, along with rim spaces, can highlight challenges and areas of concern for rim seals. Diverging shell walls will put stress on rim seals. As the envelope widens across opposite points, the compression force on the rim seal lessens equally. This lower compression force can allow additional movement of the rim seal and puts the rim seal at risk of exceeding the top-end tolerance at either radial (**Figure 6**).

Converging shell walls also poses a challenge for rim seal navigation. As shell walls converge, care must be taken to ensure the rim spaces will allow passage of the rim seal through the narrowing rim space. If convergence is severe, the collapsed rim seal may not be able to pass through the space and cause failures, as indicated in the previous section (**Figure 7**).

Verticality and roundness are complex, and each tank has a unique profile and set of circumstances to navigate. Laser scanning and other dimensional data will help determine the cause of failures and enable recognition of potential failures before service. All tanks, especially those presenting these challenges in verticality and roundness, must have seals that are designed specifically for the uniqueness of the tank. A seal manufacturer should suggest and provide custom designs of seal components to ensure the rim seal can navigate below low-end and above top-end tolerance issues as needed. Failures caused by verticality and roundness are typically preventable and can be avoided with sound inspection measurements and proper rim seal design.

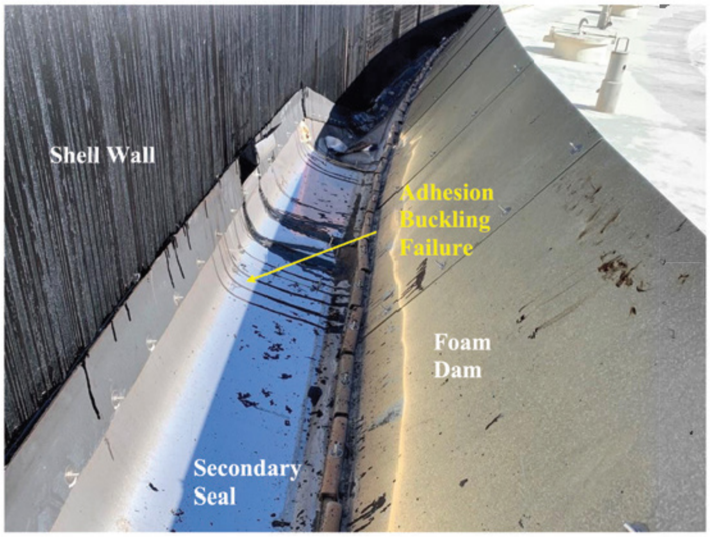

Figure 8. Buckling of metallic secondary seal compression plate due to polymer extrusion adhesion to shell wall.

Adhesion: Wiper Tips

It is also possible for the product being stored to physically interact with the rim seal. Some stored products, like certain crude oils, can exhibit properties that make the product viscous or tacky. This can impact both the primary and secondary rim seals, but in particular, it can be challenging for steel secondary seals with polymer extrusions. If conditions allow, a product that is tacky and clings to the shell wall can interact with the polymer extrusion and result in adhesion of the extrusion to the shell wall. If the polymer extrusion is partially or fully adhered to the shell wall, this can put extreme stress on the secondary seal steel compression plates. Especially concerning adhesion, a filling cycle following a period of static storage exerts vertical forces on the compression plate, which may lead to bending and subsequent failure of the secondary seal. As opposed to rollover with the extrusion pointing downward towards the rim, the resulting bending causes an upward arc of the secondary seal due to the buckling of the metallic compression plate (**Figure 8**).

Temperature, extended rim spaces, and the prolonged static state of the floating roof can all add to the risk of adhesion with certain stored products. Adhesion requires consultation with the seal manufacturer to understand the product stored and conditions promoting this phenomenon in order to mitigate future failures. In the case of adhesion, specific steel secondary seals should be utilized that are specifically designed to counteract adhesion breakout forces. Seal manufacturers should be consulted when concern of adhesion exists.

External Forces

External forces will occasionally cause failures in rim seals. These forces can include physical damage from objects and weather events. Physical damage can be shown through isolated damaged sections of the rim seal, such as buckling, crumpling, or other means of localized damage. This damage can also lead to the propagation of damage around the seal. When suspecting physical damage, inspection should include looking for obstructions on the shell wall, such as weld seams and laps, as well as obstructions above the floating roof. The investigation should include a review of fill heights and the history of roof movement. Damage from weather phenomena can be determined through known weather events. Rim seals must be selected for the environment, especially in external floating roofs. Wind, snow, ice, and heavy rains can all impact rim seals if not properly designed for extreme weather environments.

Conclusion

Aboveground storage tank floating roof rim seals perform a difficult but essential job in a hazardous environment. The rim seal must resist degradation, navigate complex geometries, sometimes resist adhesion, and withstand or avoid external forces. In most cases, rim seals can navigate these demands, but failures sometimes occur. Breaking down the causes of failures is important to ensure a seal can be designed and installed to mitigate future failures. Failures of rim seals are time-consuming and damaging to operations and the environment. The challenges rim seals face require tank owners to demand a rim seal designed properly for use and for the specific tank. Opting for a seal manufacturer that custom-engineers each design to fit the specific tank parameters significantly diminishes the likelihood of rim seal failures by effectively mitigating associated risk factors. For these reasons, rim seals should not be considered a commodity nor a "one size fits all," but as an engineered product that reduces risk and ensures long-lasting, reliable, and profitable performance. ■

For more information on this subject or the author, please email us at inquiries@inspectioneering.com.

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Adam Vance is an experienced leader, technical expert, and innovator in the petroleum industry. In his current executive management role at Mesa Industries, Inc., Adam leads business innovation, engineering, quality, operations, and sales. Adam's team designs and manufactures top-quality, custom-engineered solutions for tank drain hoses, seals, and fabrics. He consults in and out of the field with global oil industry customers to find innovative storage solutions. Adam also led the successful integration of industry leader WG Seals into Mesa's Engineered Tank Products division, including the recent launch of ClipLock™, a patent-pending fabric attachment system, and FlexCore™, a patent-pending liquid-mounted seal.