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Khurais Role in Development and Deployment of NM Application in Oil and Gas Industry Which will Paves the Way to the New Arena

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Abstract

As Khurais Producing Department (KhPD) at Saudi Aramco (SA), we've been on an exciting journey of innovation over the past years. We've undertaken a massive deployment effort to integrate new Non-Metallic (NM) piping systems into our operations - and let me tell you, it's been a game-changer for the industry.

One of our biggest successes has been the introduction of the first Sour High-Density Polyethylene (HDPE) lining technology in our crude oil flowlines. This has resulted in a staggering 90% reduction in replacement costs and extended the life of our assets. But we didn't stop there - we've also implemented a new protective system against corrosion, the rotolining of fittings, which is proving to be much more robust than traditional coating methods.

But wait, there's more! We've taken our non-metallic piping deployment efforts to the next level by installing the first-ever Thermoplastic Composite Pipe (TCP) in onshore facility for hydrocarbon applications at one of our Oil Producer facilities. This TCP technology can withstand pressures up to 5000 psi, which is far superior to the Reinforced Thermoplastic Pipes (RTP) we've used in the past. We're really excited about this field trial, as we believe it will inspire TCP manufacturers to develop even more competitive products that can push the boundaries of what's possible.

And that's not all! We've also executed a brand-new non-metallic initiative - the "ETFE Roto-Lined Non-Metallic 8" 90-degree Elbow." This elbow is made of Carbon Steel but features a non-metallic liner, which we believe is the ultimate solution to combat corrosion and erosion. This is the first implementation of its kind within our company, and we're confident it will pave the way for new and innovative applications across the board.

In summary, the Khurais Producing Department has been on a remarkable journey of innovation, and we're proud to have deployed several first-of-their-kind products and applications. From Sour HDPE lining to Thermoplastic Composite Pipes and Roto-Lined Elbows, we're constantly pushing the boundaries of what's possible in the Oil and Gas industry. Our team's dedication and passion for innovation have truly paid off, and we can't wait to see what the future holds.

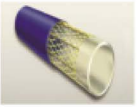





Figure 1—Thermoplastic Composite Pipe Installation project at KHRS-35



Figure 2—Ethylene Tetrafluora Ethylene roto-lined project at KHRS-151

Table 1—nonmetallic technology comparison.

Product	Service	Current Approved Operating Envelope	Envelop Expansion Initiatives	Unit Cost (\$/M)
 RTP (Fiber Reinforced)	<ul style="list-style-type: none"> Water, Oil and Gas, Gas Condensate Oil: up to 10% H2S Gas & Gas Condensate: up to 1% H2S 	Up to 4"; 2250 Psi, 180F Up to 6"; 1500 Psi, 180F	<u>Under trial</u> <ul style="list-style-type: none"> First Flowline rehab projects, 	35-100 \$
 RTP (Steel Reinforced)	<ul style="list-style-type: none"> Water, Oil, Gas and Gas Condensate (sweet applications only) 	Up to 6"; 3000 Psi, 194F Up to 8"; 3000 Psi, 194F	<u>Under trial</u> <ul style="list-style-type: none"> First Rehab RTP in under road is under review 	150-350 \$
 TCP	<ul style="list-style-type: none"> Water, Oil, Gas, Gas Condensate (up to 10% H2S) 	up to 5"; 3000 Psi, 248F	<u>Under trial</u> <ul style="list-style-type: none"> First onshore trail test was conducted on KHRS-35 	1000\$
 HDPE Lining	<ul style="list-style-type: none"> Water 	Up to 24"; 3500 Psi, 180F Up to 42"; 3000 Psi, 180F	<u>Under trial</u> <ul style="list-style-type: none"> Highway crossing rehab projects with PE-RT, ETC: Q3, 2022. First Sour service HDPE lining to expand rehab envelop to sour services in KHRS-148. First ETFE Rotolined test to unlock high temp applications up to 250 F for wellhead piping in KHRS-151. ETC:Q2,2022. 	10-50 \$

Introduction

It's an exciting time in the Khurais Producing Department (KhPD) at Saudi Aramco. Over the past few years, our team has been leading a comprehensive initiative to integrate cutting-edge non-metallic (NM)

technologies across our operations. This ambitious effort was sparked by the Southern Area Oil Operation NM committee, who identified 28 specific projects that could help us overcome some of our most pressing challenges.

The strategies we're pursuing fall under six key focus areas:

1. Actively seeking out and maximizing the use of the latest NM products and technologies.
2. Collaborating closely with our Engineering Services team to expand the boundaries of what's possible with these materials.
3. Approving a wider range of vendors to install these new NM solutions.
4. Rigorously qualifying and certifying contractors and maintenance technicians to ensure top-notch execution.
5. Driving greater awareness and training for all our key stakeholders.
6. Actively participating in industry workshops and conferences, and publishing our learnings to help advance the state of the art.

These multi-pronged efforts have allowed us to tackle some critical challenges, from corrosion issues (like microbiologically-induced corrosion and design deficiencies) to geographical obstacles (such as highway/railway crossings and complex pipeline routing).

One of our biggest successes has been the widespread adoption of reinforced thermoplastic pipe (RTP) technology. High leak rates in our carbon steel pipelines prompted us to launch a major campaign to replace them with RTP alternatives. Our first RTP trial was way back in 2004 for a low-pressure water line, and now over 60% of Khurais' 1000+ km of oil flowlines utilize this game-changing material.

The benefits of RTP are truly remarkable - superior corrosion resistance, lightweight construction, flexibility, and the ability to withstand high pressures and temperatures. It's no wonder this technology has gained such widespread traction, not just within KhPD, but across the entire oil and gas industry.

However, we're not resting on our laurels. We know there are still limitations in implementing a fully non-metallic system from wellhead to trunk line. Existing NM technologies are constrained by pressure and temperature ratings, and in some cases, monopolized by specific vendors in the Middle East. Overcoming these barriers is a key focus area for us as we continue to push the boundaries of innovation.

Overall, KhPD's proactive implementation of these NM initiatives has cemented our reputation as a pioneer within Saudi Aramco and one of the global leaders in applying non-metallic applications in the oil and gas sector. It's been an incredible journey so far, and we can't wait to see what the future holds.

Objectives/Scope

The proposed research paper seeks to undertake a comprehensive examination of the strategic significance underlying the pioneering efforts of Khurais Producing Department (KhPD) in the development and deployment of non-metallic piping solutions within the oil and gas industry. The primary objective of this study is to delineate, in meticulous detail, the profound impact that this innovative initiative has had on enhancing operational reliability and fostering sustainable best practices across the sector.

The paper will trace the remarkable journey of this groundbreaking endeavor, chronicling its inception and subsequent evolution into industry-leading applications. It will delve deep into the alignment of this initiative with the broader environmental sustainability objectives, highlighting how the adoption of non-metallic piping materials has contributed to reducing the carbon footprint and promoting eco-friendly operations within the oil and gas domain.

Through a rigorous analysis of the strategic rationale, technical advancements, and operational benefits associated with KhPD's pioneering work, the proposed paper aims to provide valuable insights and a comprehensive understanding of the transformative role played by this department in shaping the future of the oil and gas industry's sustainability practices. The study will serve as a seminal contribution to the body

of knowledge, illuminating the path forward for other industry players seeking to emulate and build upon the successes achieved by KhPD.

Methods, Procedures, Process

The strategic approach undertaken by the Khurais Producing Department (KhPD) was anchored in the establishment of a dedicated Southern Area Oil Operation Non-Metallic Committee. This cross-functional team has spearheaded an extensive portfolio of 28 distinct initiatives, spanning a diverse array of areas - from in-plant operations and onshore upstream projects to rehabilitation efforts and downhole applications.

The adopted methodology has been resolutely multifaceted, encompassing a holistic strategy aimed at driving progress and innovation across the organization. This has included:

- Leveraging the latest technological advancements to identify and maximize the utilization of cutting-edge non-metallic products.
- Collaborating closely with Engineering Services partners to expand the product envelope and approve a wider roster of vendors, thereby enhancing supply chain resilience for non-metallic installations.
- Rigorous qualification and certification processes for contractors and maintenance technicians, to ensure the highest standards of workmanship for all non-metallic applications.
- Comprehensive awareness-building and training programs for key stakeholders, equipping them with a deep understanding of the benefits and proper deployment of non-metallic materials.

Furthermore, the department's strategic approach has been underpinned by a steadfast commitment to active participation in industry workshops and conferences, as well as the publication of technical papers. This collaborative mindset and knowledge-sharing ethos have been instrumental in shaping the strategic direction and implementation of this transformative initiative, while also fostering a culture of continuous improvement across the organization.

The synergistic integration of these multifaceted elements has been the driving force behind KhPD's ability to adapt new technologies and address critical challenges, primarily related to corrosion and geographical obstacles. This holistic strategy and unwavering dedication to advancing the industry's understanding of non-metallic solutions have been the hallmarks of this pioneering endeavor.

Results, Observations, Conclusions

The strategic initiatives undertaken by the Khurais Producing Department (KhPD) have yielded truly transformative results. The large-scale deployment of non-metallic piping solutions across the oil network has been met with remarkable success, including a 50% reduction in corrosion-related defects and the extension of over 1,000 kilometers of the oil infrastructure. This seamless transition from successful pilot trials to full-scale implementation serves as a testament to the department's steadfast commitment to innovation and its ability to drive tangible, impactful change.

Furthermore, the KhPD initiatives have introduced a suite of novel product solutions, such as ETFE root-lined elbows and thermoplastic composite pipe, which have significantly expanded the application envelope for non-metallic technologies within the industry. These advancements have positioned the department as a groundbreaking pioneer, pushing the boundaries of what is possible with non-metallic materials and elevating the industry's understanding of their potential.

The crowning achievement of the department's efforts is the establishment of the state-of-the-art Non-Metallic Test Hub at KHRS-573, which has emerged as a pioneering facility for in-situ RTP (Reinforced Thermoplastic Pipe) testing. This innovative facility, which encapsulates RTP within carbon steel pipes to mitigate environmental impact, has become a hub of cutting-edge research and development, driving the industry's understanding and adoption of non-metallic solutions to new heights.

Collectively, these transformative advancements have led to a substantial reduction in the carbon footprint, estimated at an impressive 151 million tons, by circumventing the emissions associated with the traditional manufacturing and maintenance of steel pipes. This remarkable achievement underscores the department's unwavering commitment to environmental sustainability and its ability to drive meaningful change within the oil and gas sector, positioning it as a beacon of innovation and a catalyst for the industry's transition towards a more sustainable future.

Novel/Additive Information

This research paper presents a groundbreaking and novel body of information by chronicling the industry's first comprehensive shift towards the widespread adoption of non-metallic piping solutions. Through a meticulously documented account, the paper emphasizes the pivotal role played by innovative materials in achieving long-term sustainability and reliability within the oil and gas operations landscape.

By delving deeply into the strategic initiatives, technological advancements, and operational impacts of this transformative shift, the paper offers a comprehensive understanding of the factors driving this industry-wide transition. It sheds light on the multifaceted benefits that have emerged from the deployment of non-metallic piping, including enhanced corrosion resistance, extended operational lifespan, and significant reductions in carbon footprint.

Moreover, the paper underscores the critical importance of innovative materials in enabling the oil and gas sector to align its practices with the overarching objectives of environmental sustainability. It highlights how the successful integration of non-metallic solutions has paved the way for a more resilient and eco-conscious future, ultimately contributing to the industry's long-term viability and responsible stewardship of natural resources.

Through its meticulous documentation and in-depth analysis, this research paper serves as a groundbreaking and invaluable resource, offering pioneering insights that will shape the industry's strategic approach to infrastructure development, asset management, and sustainable operations in the years to come. The paper's comprehensive and forward-looking perspective positions it as a seminal work that will undoubtedly influence and inspire the industry's journey towards a more sustainable and technologically advanced future.

Initiative

Non-metallic Testing Hub. At our company, we are committed to driving innovation and localization in our operations. In support of this strategic direction, we have developed a pioneering Non-Metallic Testing Hub at one of our Khurais wells. This state-of-the-art facility allows us to rigorously evaluate non-metallic materials and technologies in a real-world, harsh environment without compromising the surrounding ecosystem.

The centerpiece of this testing hub is the encapsulation of non-metallic pipes within carbon steel casings. This innovative approach enables us to subject the materials to the exact conditions they would face in our oil wells, including exposure to high pressure and potential H₂S (hydrogen sulfide) exposure. Our testing hub is equipped with advanced pressure indicators and H₂S sensors, providing us with critical data and early warning indicators in the event of any leakage or failure.

We believe this testing hub represents a significant step forward in our quest for more sustainable and cost-effective non-metallic solutions. By providing a dedicated platform for evaluating these materials, we can ensure they meet the stringent performance and safety requirements of our operations before deploying them in the field.

The testing process typically follows a rigorous sequence. First, we thoroughly evaluate the material in our testing hub, subjecting it to the most demanding conditions it would encounter. If the material fails to meet our established criteria, we work closely with our vendors to refine the product and resubmit it

for further testing. This iterative process continues until we arrive at a solution that is both successful and applicable to our operational needs.

Once a non-metallic material has successfully navigated the testing hub, we then proceed to a year-long experimental deployment in one of our oil wells. This additional step allows us to validate the material's performance in a real-world, mission-critical environment before giving it the final stamp of approval for full-scale implementation.

By taking this rigorous, collaborative approach, we are not only advancing the state of non-metallic technologies but also ensuring the safety, reliability, and environmental sustainability of our operations. The Non-Metallic Testing Hub stands as a testament to our commitment to innovation, localization, and responsible resource management.

Steel Reinforced Composite Pipe. S-RTP flexible pipe is made up of different several layers. The main components are leakproof thermoplastic barriers and corrosion-resistant steel strip/wires. The helically wound steel reinforcement gives the structure its high-pressure resistance and excellent bending characteristics, thus providing flexibility and superior collapse resistance.

A thorough technical analysis in conjunction with Saudi Aramco experience on utilization of fiber reinforced thermoplastic pipe was completed and accordingly, s-RTP has been selected for further evaluation and trial.

The use of a nonmetallic steel reinforced thermoplastic pipe (s-RTP) in lieu of a traditional carbon steel pipe will eliminate corrosion problems in the water injection laterals and enhance the long-term integrity and reliability. S-RTP will significantly reduce installation, maintenance and operation cost. A high cost savings is anticipated.

The implementation of s-RTP flowline is in-line with Company Strategy to promote and expand the utilization of nonmetallic products in Saudi Aramco. It also presents an opportunity for localization since s-RTP piping material can be used in the other demanding applications as well.

The main economic advantages are: Install in 40-80% of the time, 35-65% lower installed cost than welded steel line pipe, Minimal manpower and equipment requirement, no welding, field bending, coating or X-ray costs. And for the technical advantages: Increased reliability, Improved safety/environment, Corrosion resistance and smaller right of way.

Ethylene tetrafluoro ethylene (ETFE) roto lining. At Khurais Producing Department, we are continuously exploring innovative ways to enhance the reliability and sustainability of our operations. In 2021, we took a significant step forward by becoming the first in our company to deploy the cutting-edge ETFE (Ethylene Tetrafluoro Ethylene) roto-lining technology for our sour crude service applications.

This initiative was the result of a collaborative effort between our Khurais Producing Department, the central engineering team, and our trusted vendors. Our goal was to find a comprehensive solution that could cover the entire well piping system, from the Christmas tree to the trunk line, effectively addressing the challenges of corrosion and erosion.

The ETFE roto-lining technology has emerged as a game-changer in our quest for more durable and long-lasting piping systems. The key innovation lies in the application of a non-metallic liner within a carbon steel elbow, using a specialized flangeless welding procedure. This approach is considered a permanent solution to the persistent issues of microbial-induced corrosion (MIC) on our underground carbon steel flowlines.

Beyond the corrosion mitigation, this initiative also provided us with an opportunity to evaluate the ETFE material's compatibility with our harsh operating environment, ensuring the retention of the liner's essential properties. Additionally, the use of a flangeless system has helped us overcome the persistent challenges of underground flange leaks, further enhancing the reliability and safety of our piping infrastructure.

Upon successful completion of this pilot project, we are poised to introduce a fully non-metallic piping system for our oil flowlines, from the wellhead to the tie-in point. The ETFE roto-lining technology is

capable of withstanding temperatures up to 180°F and pressures up to 1500 PSIG (Maximum Allowable Operating Pressure), making it a versatile and robust solution for our operations.

This pioneering effort at Khurais Producing Department is not only a testament to our commitment to innovation but also a significant step towards a more sustainable and corrosion-resistant future for our industry. By paving the way for new applications company-wide, we are confident that this technology will contribute to the enhanced reliability, safety, and environmental stewardship of our overall operations.

High Density Polyethylene (HDPE) lining. At Khurais Producing Department, we are constantly seeking innovative solutions to enhance the efficiency and sustainability of our operations. In line with this commitment, we have taken the initiative to explore the application of High-Density Polyethylene (HDPE) lining technology for our hydrocarbon service, marking a significant milestone as the first implementation of its kind within our company.

Traditionally, the use of HDPE lining has been predominantly in water service applications. However, we recognized the potential benefits of extending this technology to our sour crude service, where corrosion and erosion pose significant challenges.

The objective of this groundbreaking trial is to evaluate the performance and cost-effectiveness of the non-metallic HDPE liner in our harsh operating environment. The HDPE liner was installed along the entire flowline, encompassing both the piping and the fittings, providing a comprehensive solution to address the corrosion issues.

To further enhance the reliability and safety of this system, we have implemented a passive injection system from both ends of the flowline. This innovative feature helps to remove any potential gas accumulation between the HDPE liner and the carbon steel casing, ensuring the continued integrity of the lining.

The benefits of this HDPE lining technology are multifaceted. First and foremost, we anticipate a significant cost savings of up to 70% compared to the traditional Riser Tubing Pipe (RTP) approach. Secondly, by utilizing the existing carbon steel flowlines, we can expedite the installation process and eliminate the need for complete pipeline replacements, thereby reducing downtime and operational disruptions.

Furthermore, the versatility of the HDPE lining extends to its scalability, with the capability to be applied to pipeline sizes up to 42 inches in diameter. Additionally, the system can withstand temperatures up to 180°F and pressures up to 1500 PSIG, making it a robust and adaptable solution for our sour crude service applications.

This pioneering initiative at Khurais Producing Department not only showcases our commitment to innovation but also demonstrates our dedication to enhancing the reliability, cost-effectiveness, and environmental sustainability of our operations. By being the first in our company to deploy the HDPE lining technology for sour crude service, we are paving the way for broader adoption and unlocking new possibilities for the future of our industry.

Thermoplastic Composite Pipe TCP. At Khurais Producing Department, we are committed to exploring innovative solutions that address the operational challenges we face. One such initiative is the pioneering deployment of Thermoplastic Composite Pipe (TCP) technology in our onshore crude oil flow lines.

Traditionally, our crude oil flow lines have relied on carbon-steel piping, which can be susceptible to corrosion and erosion, particularly in the harsh operating conditions we encounter. To overcome these limitations, we have taken the bold step of installing a 1.4 km TCP line, marking the first-ever onshore application of this technology in the world.

The TCP is a non-metallic, fully-bonded, multi-layer thermoplastic composite pipe, where the layers are melt-fused together. This unique construction allows the TCP to be lightweight, strong, flexible, and durable, addressing the pressure and temperature limitations we have faced with traditional piping solutions.

Before deploying the TCP in the field, we conducted extensive testing at our Non-metallic Testing Hub, where the pipe successfully passed all the required assessments. This gave us the confidence to proceed with the field installation, which was completed in March 2022.

The performance of the TCP in our onshore crude oil application has been exceptional. Since its commissioning, the well equipped with the TCP has not experienced any leaks or shutdowns, providing a significant improvement in our Health, Safety, Security, and Environment (HSSE) performance. This, in turn, has positively impacted our operational efficiency and sustainability, as we have been able to maintain continuous production and avoid the need for costly repairs and downtime.

The TCP technology was installed in KHRS-35 for approximately 1.4 KM to replace the corroded 10-inch carbon steel flowline. The TCP can be manufactured in continuous lengths of 3,000 to 6,000 meters or as per the required length requested by the client. However, for the purpose of this trial test the TCP pipe was distributed into three (3) reels in order to have two (2) in-line connectors to test the connectors and ensure no leaks will occur in longer length flowlines in future deployments. Additionally, long length pipe can only be transported to offshore only.

Furthermore, the implementation of the TCP has reduced our inspection requirements, as the visual inspection of the coupling connections is now sufficient, compared to the more extensive checks required for traditional carbon-steel piping.

In terms of sustainability, the Khurais Producing Department is proud to note that Saudi Aramco holds a 35% stake in the TCP manufacturing company, showcasing our commitment to developing and supporting local non-metallic solutions.

Moving forward, we are actively collaborating with our Central Engineering team to explore the potential of extending the use of TCP technology to our wellheads and tie-ins. This expansion would provide a permanent solution to the corrosion and erosion challenges we face, further enhancing the reliability and longevity of our production infrastructure.

The successful implementation of TCP in our onshore crude oil flow lines is a testament to our dedication to innovation and our relentless pursuit of sustainable solutions. By pioneering the use of this cutting-edge technology, we are paving the way for broader industry adoption and setting new benchmarks for operational excellence and environmental stewardship.

Fully bonded RTP. In our ongoing efforts to innovate and address the operational challenges faced in the oil and gas industry, the Khurais Producing Department has taken a pioneering step in introducing a new Reinforced Thermoplastic Pipe (RTP) solution from the manufacturer Future Pipe Industry.

One of the common dilemmas encountered with non-metallic pipe applications has been the issue of gas permeability, which can compromise the integrity and performance of the piping system. To overcome this challenge, we have worked closely with Future Pipe Industry to develop a fully bonded RTP solution.

The key differentiator of this new RTP product is its fully bonded construction, which helps to significantly reduce the gas permeability that has been a concern with previous non-metallic pipe offerings. This innovative design addresses a critical issue that has hindered the widespread adoption of non-metallic pipes in our industry.

Before deploying the fully bonded RTP in the field, we conducted thorough testing at our in-house Non-metallic Testing Hub, where we subjected the pipe to the harsh operating conditions it would encounter in our operations. The initial two trials were not successful, but the third iteration of the fully bonded RTP design proved to be a resounding success.

With this validation, we proceeded to deploy the fully bonded RTP as a pilot project on one of Khurais wells. The performance of this installation has been closely monitored, and we are pleased to report that the pipe has demonstrated its ability to effectively address the gas permeability challenge, ensuring the integrity and reliability of our production infrastructure.

This pioneering initiative by the Khurais Producing Department showcases our commitment to exploring innovative solutions that can enhance the performance and longevity of our non-metallic pipe applications. By collaborating with forward-thinking manufacturers like Future Pipe Industry, we are driving the development and adoption of cutting-edge technologies that will shape the future of our industry.

As we continue to evaluate the long-term performance of the fully bonded RTP in our operations, we remain steadfast in our pursuit of sustainable and efficient solutions that will optimize our production processes, improve our environmental footprint, and solidify our position as industry leaders in innovation.

Conclusion

In conclusion, the groundbreaking work undertaken by Khurais Producing Department in deploying the non-metallic solution has showcased our unwavering commitment to innovation and sustainability.

The successful implementation of this non-metallic pipe technology has yielded significant environmental benefits, including a remarkable reduction in carbon emissions. By eliminating the emissions associated with the manufacturing of steel pipes, the installation process, and the maintenance and repair activities.

Furthermore, our assessment and targeted replacement of high-risk carbon steel flow lines with non-metallic alternatives have resulted in a notable 70% reduction in the total number of leaks compared to the previous year. This not only enhances the reliability and safety of our operations but also demonstrates the superior performance of these advanced non-metallic pipe solutions.

Importantly, the elimination of dangerous "hot work" activities, such as welding, during the installation and repair of these non-metallic pipes has effectively removed the smoke emissions that were traditionally associated with such processes. This further underscores the environmental benefits and the positive impact on the health and safety of our workforce.

Our accomplishments in this field have been widely recognized both within our company and on national and international platforms. This recognition has solidified our position as industry leaders, setting a benchmark for the oil and gas sector and supporting the localization efforts to promote the wider adoption of such innovative technologies.

As we continue to push the boundaries of what is possible, we remain steadfast in our pursuit of sustainable solutions that not only address operational challenges but also contribute to a cleaner and more environmentally responsible future. This pioneering work in non-metallic pipe applications exemplifies our unwavering commitment to driving positive change and shaping the industry's trajectory towards a greener and more efficient tomorrow.