

INCOMING INSPECTION REPORT

UNEW-Certified Refurbishment at EthosEnergy's World-Class Facility

UNEW's capital part refurbishments are fundamentally driven by our proprietary technologies, engineering standards, and strict QA/QC procedures. While our standard practice is to carry out all refurbishments at our U.S. facility, due to geopolitical restrictions and national security concerns, parts originating from certain countries in Asia are not permitted to enter our United States Facility for repair.

To maintain the highest quality of service under these constraints, UNEW has partnered with EthosEnergy, headquartered in the United Kingdom, to carry out refurbishments on our behalf. EthosEnergy operates one of the most technologically advanced turbine repair facilities in the world, featuring up-to-the-art equipment, automated precision systems, and industry-leading repair capabilities.

All refurbishment activities at EthosEnergy are performed in full compliance with UNEW's proprietary repair technologies, technical brochures, and rigorous QA/QC protocols. EthosEnergy executes the physical repair processes, but the repair methodology, quality benchmarks, material controls, and final acceptance criteria are strictly defined, validated, and enforced by UNEW.

Customer	Nghi Son Refinery and Petrochemical, LLC.
Customer PO Number	770682
Part Description	Frame 6FA MNQC Syngas Dual Fuel Nozzles
Report No	AB9015557 – 250919 Rev 0
Report Date	October 1, 2025
Author	Liam Watson

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1. Overview and Initial Workscope

A complete set of 6 x Frame 6FA MNQC Syngas Dual Fuel Nozzles were inducted into the EthosEnergy Accessories and Components Aberdeen facility on the 8th of August 2025. The following report documents the overhaul effort up to and including dimensional and visual inspection of all components, along with the recommended repairs required in order to return the nozzles to a serviceable condition.

The incoming work scope is summarized as follows:

- Record assembly P/Ns and S/Ns
- Borescope Inspection
- As-received testing
- Disassembly
- Clean with alkaline cleaner and rinse
- Pressure test
- Detailed inspection
- NDT
- Report findings and repair recommendation

2. Incoming Part Number & Serial Number Information

Part Number	Serial Number	Part Description	Comments
119E9942G033	10844371	Frame 6FA MNQC Syngas Dual Fuel Nozzles	Nozzles received with evidence of DPI being performed – See Appendix for photographs.
	10844372		
	10844373		
	10844374		
	10844375		
	10844376		

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3. Incoming Flow Tests

Assembled Flows

Serial Number	Natural Gas @ 1.25PR	Syngas @ 1.25PR	N2/Steam @ 1.25PR	Liquid Fuel @ 100psig	Water @ 100psig
10844371	0.10143	0.34556	-	1815	2955
10844372	0.10763	0.35401	-	2181	2983
10844373	0.09882	0.35548	-	1894	2948
10844374	0.08163	0.38528	-	1056	2705
10844375	0.07039	0.39020	-	2021	3000
10844376	0.10479	0.36387	-	1994	2874
Average	0.09411	0.36573	-	1826	2910
Maximum	0.10763	0.39020	-	2181	3000
Minimum	0.07039	0.34556	-	1056	2705
Range (%)	39.57%	12.21%	-	61.58%	10.13%

*All gas and air flows are reported in effective area (in²)
All liquid and water flows are reported in pounds per hour (PPH)*

Discussion of primary test results

During detailed inspection, several consumable parts were found to be far more deteriorated than anticipated, with extensive erosion and surface damage requiring replacement. The overall condition of the nozzles indicates that multiple components will require Heavy and light-heavy repair, beyond the normal scope of medium refurbishment. Despite these issues, all tested passages are expected to be restored to within specification and to a tight flow spread following thorough cleaning, the recommended heavy repairs outlined in Section 4, and the final flow and calibration process.

4. Inspection Findings & Recommended Repairs

4.1. Consumable part Replacement (medium repair/inclusive)

Part Description		Quantity Per Nozzle	Quantity Total
1	End Cover Steam Plate E-Seal	1	6
2	Steam Inlet Blank Seal	1	6
3	Liquid Cart. Crush Seals	6	36
4	Water Cart. Spiral Wound Gasket	6	36
5	Fuel Distribution Valve O-Ring Seal A	2	12
6	Fuel Distribution Valve O-Ring Seal B	6	36
7	Fuel Distribution Valve Spring Seal	1	6

During the inspection, several consumable components were identified as requiring replacement to restore proper sealing, flow control, and mechanical integrity of the fuel nozzle assemblies. These items are classified under **medium repair** scope and include seals, gaskets, and O-rings that experience thermal fatigue, compression wear, and material degradation through normal operation.

The following parts will be replaced as part of this medium repair activity:

- **End Cover Steam Plate E-Seal** – replaced to ensure tight sealing of the end cover under high steam pressure conditions.
- **Steam Inlet Blank Seal** – replaced to prevent leakage at the steam inlet interface.
- **Liquid Cartridge Crush Seals** – renewed to maintain proper sealing between liquid cartridge interfaces, preventing cross leakage of fuel and cooling media.
- **Water Cartridge Spiral Wound Gaskets** – replaced to maintain the high-pressure water sealing performance and prevent erosion at sealing faces.
- **Fuel Distribution Valve O-Ring Seals (Type A and Type B)** – replaced to prevent fuel leakage and maintain distribution integrity within the valve assembly.
- **Fuel Distribution Valve Spring Seals** – replaced to ensure reliable valve movement and prevent internal leakage under cyclic pressure loads.

All the above components are **standard consumable parts** included in the medium repair package. Their replacement will restore the original design clearances and sealing efficiency, ensuring stable operation and proper combustion performance of the gas turbine fuel nozzle assemblies.

4.2. Heavy Repair & Part Replacements

During the inspection, several critical fuel nozzle components were found to have suffered severe thermal distress, erosion, and material degradation beyond refurbishable limits. These conditions necessitated replacement under the **heavy repair scope** to restore the mechanical and flow-path integrity of the MNQC fuel nozzle assemblies.

The following components were replaced:

- **End Cover Liner Pins** – replaced to restore the secure mechanical connection between the liner and end cover; the original pins were found worn and elongated from repeated thermal cycling.
- **Liquid Cartridge Assembly** – replaced due to internal erosion, distortion, and passage deformation that could not be corrected by standard refurbishment processes.
- **Liquid Cartridge Tip** – replaced to restore the correct spray pattern and combustion stability; previous tips exhibited surface fatigue and carbon deposition.
- **Water Cartridge Tip** – replaced as the original parts showed erosion and cracking from high-pressure water injection service.
- **Gas Swirlers (Water)** – replaced to ensure uniform air-fuel mixing; the original swirlers were oxidized and deformed by prolonged exposure to high-temperature combustion gases.
- **Water Pipework** – replaced to restore full flow integrity and eliminate thinning and corrosion observed in the previous assemblies.

Codes: ET – External Thread, ER – Eroded, Cr – Cracked, De - Deformed												
Serial Number	A-End Cover Liner Pins		B-Liquid Cartridge Assy.		C-Liquid Cartridge Tip		D-Water Cartridge Tip		E-Gas Swirlers		F-Water Pipework	
	Qty	Code	Qty	Code	Qty	Code	Qty	Code	Qty	Code	Qty	Code
10844371	1	ET			1	ER			4	Cr	3	De
10844372	1	ET			2	ER			4	Cr	3	De
10844373			6	ER	2	ER	1	ER	4	Cr	3	De
10844374	1	ET			2	ER			4	Cr	2	De
10844375					1	ER	1	ER	4	Cr	3	De
10844376	1	ET	6	ER	2	ER			4	Cr	2	De
Totals	4		12		10		2		24		16	

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To improve durability and thermal protection, a special heavy-duty coating system was applied to all critical flow and heat-exposed areas. This included:

- MCrAlY-based bond coating for oxidation and corrosion resistance.
- High-temperature ceramic topcoat (TBC) to minimize thermal fatigue and extend service life.
- Additional reinforced coating layers on end cover tips, liner pins, and cartridge assemblies to prevent erosion and carbon adhesion during high-load operation.

After reassembly, all nozzles underwent flow calibration testing to verify uniform fuel and water distribution within OEM specifications. This repair process ensures the MNQC fuel nozzles are restored to full functional integrity, offering enhanced thermal protection, reduced erosion, and extended operational life compared to standard repair methods.

4.3 Inspection Findings

a. 4 x End Cover Liner Pins were found to have stripped threads

Root Cause / Technical Explanation:

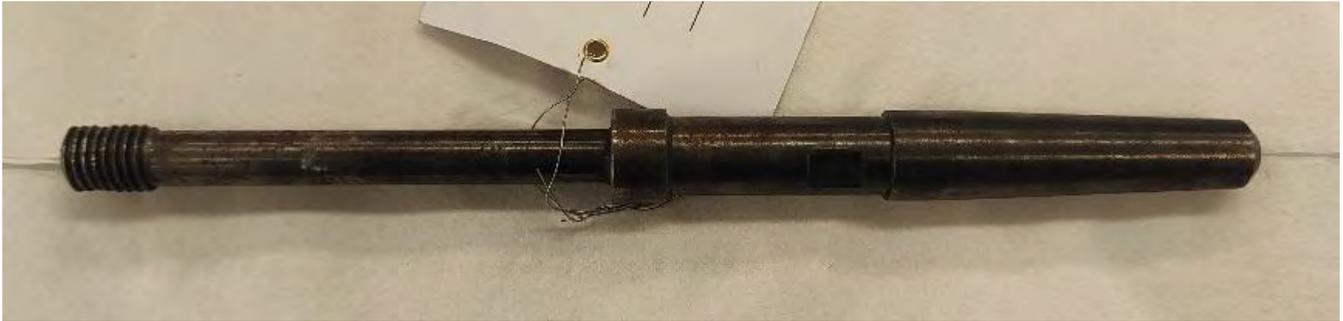
- **Repeated thermal cycling and mechanical vibration** over extended operating hours caused gradual loosening between the liner and end cover interface. The cyclic expansion and contraction resulted in micro-movement that led to thread wear and material galling.
- **High installation torque during previous maintenance** may have over-stressed the thread roots, weakening the material and making it prone to stripping during removal.
- **Carbon and oxide buildup** around the threaded sections also contributed to thread seizure, requiring additional torque during disassembly and leading to partial stripping.
- **Localized heat exposure** near the combustor end increased metal hardness differentials between the pin and the female threads, accelerating wear when subjected to vibration.

Conclusion:

The thread damage is attributed to combined effects of thermal fatigue, vibration-induced fretting, and excessive tightening during prior installation. Replacement of all affected liner pins with new components was carried out as part of the heavy repair scope to restore full mechanical integrity and secure alignment between the end cover and liner assembly.



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b. 12 x Liquid Cartridge Assemblies were found to be burnt out

During detailed inspection, twelve (12) Liquid Cartridge Assemblies were found to be beyond refurbishable condition, exhibiting severe erosion, pitting, and deformation of the internal fuel passages.

Root Cause / Technical Explanation:

- Prolonged high-temperature exposure was identified as the primary factor contributing to material degradation. Continuous operation under elevated combustion temperatures caused thermal fatigue, oxidation, and loss of coating adhesion, especially near the liquid cartridge tip area.
- Erosion and cavitation within the internal fuel passages occurred due to high-velocity liquid fuel injection, especially during transient load changes. This led to surface roughening and enlargement of metering orifices, reducing fuel flow accuracy.
- Thermal fatigue cracking propagated along cartridge walls and tip zones due to cyclic heating and cooling, particularly during frequent start-up and shutdown sequences.
- Chemical corrosion and carbon deposition from fuel impurities and incomplete combustion accelerated metal surface deterioration and internal coating breakdown.
- Misalignment and wear at sealing interfaces between the cartridge and end cover resulted in uneven load transfer and localized stress, further promoting cracking and deformation.

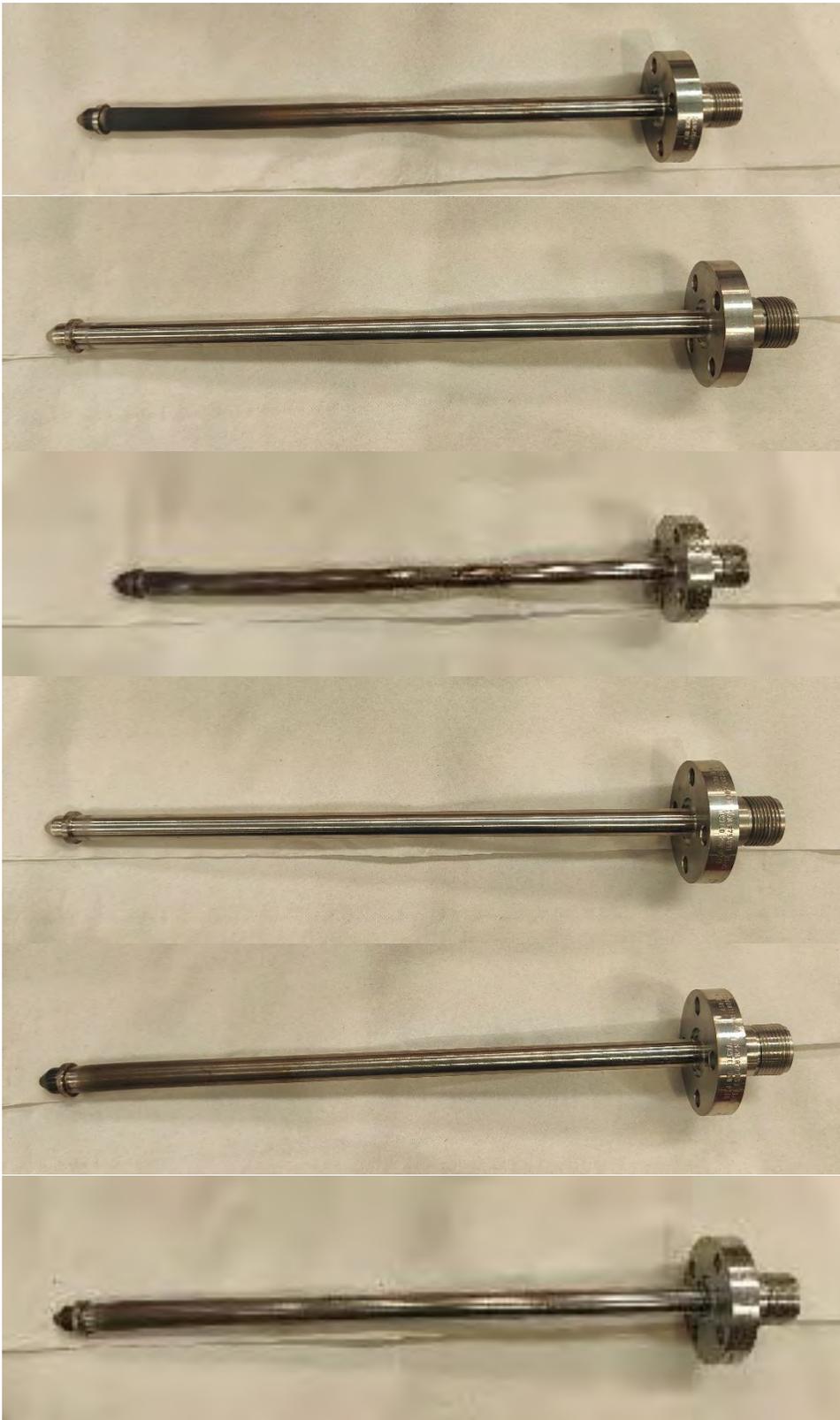
During the inspection and technical meeting, UNEW's technicians verbally explained to NSRP that the root cause was primarily high-temperature exposure in combination with normal operating erosion and aging effects. The explanation was acknowledged and understood by NSRP's representatives.

Conclusion:

The damage to the 12 Liquid Cartridge Assemblies is attributed to combined high-temperature exposure, thermal fatigue, and erosion accumulated over extended service time. These factors caused irreversible distortion and internal flow path degradation, making refurbishment impractical. Replacement of all twelve assemblies under the heavy repair scope was therefore carried out to restore proper flow geometry, spray pattern accuracy, and combustion stability in accordance with OEM-equivalent performance standards.



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c. 10 x Liquid Cartridge Tips were found to have eroded water swirl vanes.

During inspection, ten (10) Liquid Cartridge Tips were found to be severely damaged and beyond repairable condition. The affected tips exhibited significant signs of surface cracking, tip deformation, and internal erosion in the fuel discharge ports.

Root Cause / Technical Explanation:

- High-temperature exposure during extended operation was the primary cause of degradation. Continuous exposure to extreme flame temperatures led to oxidation, metal fatigue, and loss of surface integrity at the tip ends.
- Localized overheating occurred due to uneven fuel flow and combustion dynamics, causing melting and rounding of the tip edges. These effects were most pronounced in tips located near zones of high thermal flux.
- Thermal fatigue resulting from repeated start-up and shutdown cycles caused fine cracks to form along the outer surface and internal bore areas. Over time, these cracks propagated and led to structural weakening.
- Erosive wear was also evident at the metering holes, resulting from high-velocity liquid fuel streams impinging on the nozzle surfaces. This contributed to distortion of the orifice shape and inconsistent spray angles.
- Carbon deposition and coating loss were observed in several tips, indicating breakdown of the protective layer due to prolonged exposure to high heat and fuel impurities.

Conclusion:

The 10 Liquid Cartridge Tips were determined to be unfit for refurbishment due to thermal fatigue cracking, orifice distortion, and coating failure caused by high-temperature exposure and erosive operating conditions. Replacement with new components under the heavy repair scope was therefore required to restore proper atomization characteristics, fuel distribution uniformity, and overall combustion performance of the MNQC fuel nozzle assemblies.





d. 2 x Water Cartridge Tip was found to be eroded

During detailed inspection, two (2) Water Cartridge Tips were found to be eroded and worn beyond acceptable service limits. The erosion was concentrated around the discharge ports and tip faces, with evident surface thinning and loss of geometric profile.

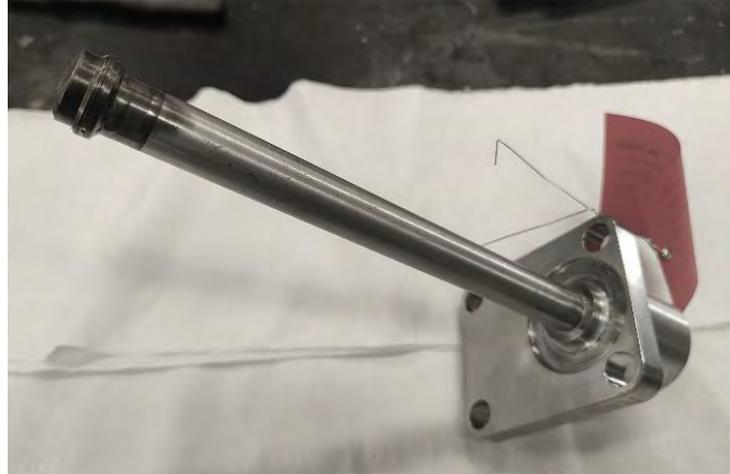
Root Cause / Technical Explanation:

High-velocity water injection during operation caused continuous impingement and abrasive wear at the tip outlets. Over time, this eroded the metal surfaces and enlarged the injection orifices, resulting in degraded spray patterns and reduced atomization efficiency.

- **High-temperature exposure** in the combustion environment accelerated surface oxidation and coating breakdown, further weakening the material and exposing the base metal to direct erosion.
- **Thermal cycling and quenching** effects during frequent startup and shutdown operations induced surface fatigue, which promoted micro-crack formation and progressive surface loss.
- **Chemical reaction** between injected water and combustion byproducts also contributed to localized corrosion, particularly in areas where the protective coating had deteriorated.

Conclusion:

The 2 Water Cartridge Tips were found to be irreparable due to severe erosion, oxidation, and loss of dimensional integrity. The damage compromised water injection uniformity and posed a risk of imbalance in combustion cooling effectiveness. Replacement with new Water Cartridge Tips under the heavy repair scope was therefore carried out to restore proper flow geometry, cooling efficiency, and stable combustion performance in accordance with OEM-equivalent standards.



e. 24 x End Cover Gas Swirlers were found to have cracking around the air outlet holes.

Root Cause / Technical Explanation:

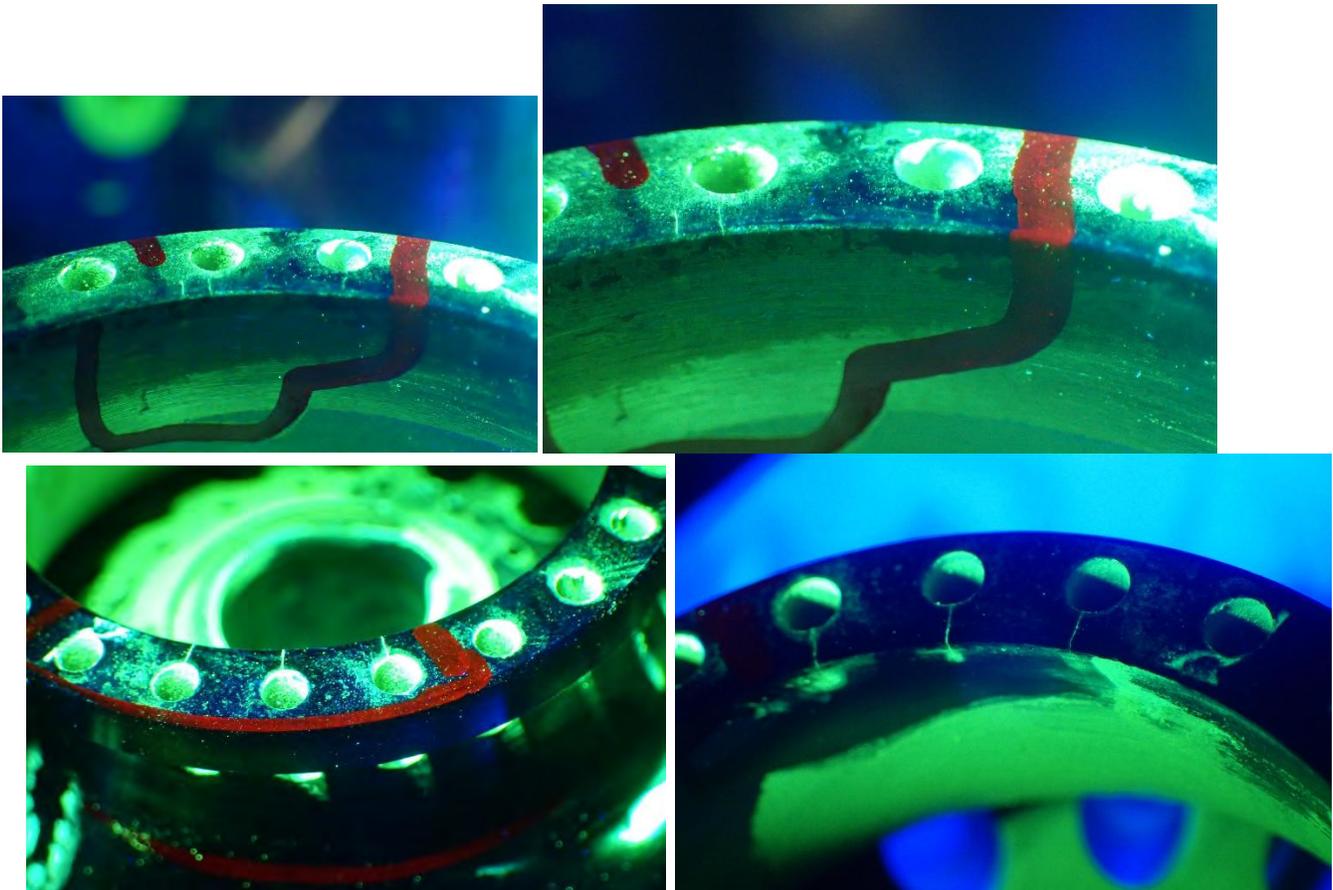
- **Thermal fatigue** was identified as the principal cause of cracking. Continuous exposure to high combustion temperatures, combined with repeated heating and cooling cycles, induced material fatigue stresses in the thin sections surrounding the outlet holes.
- **High-velocity air and fuel mixture flow** generated localized vibration and pressure pulsation at the outlet edges, which further propagated existing fatigue cracks.

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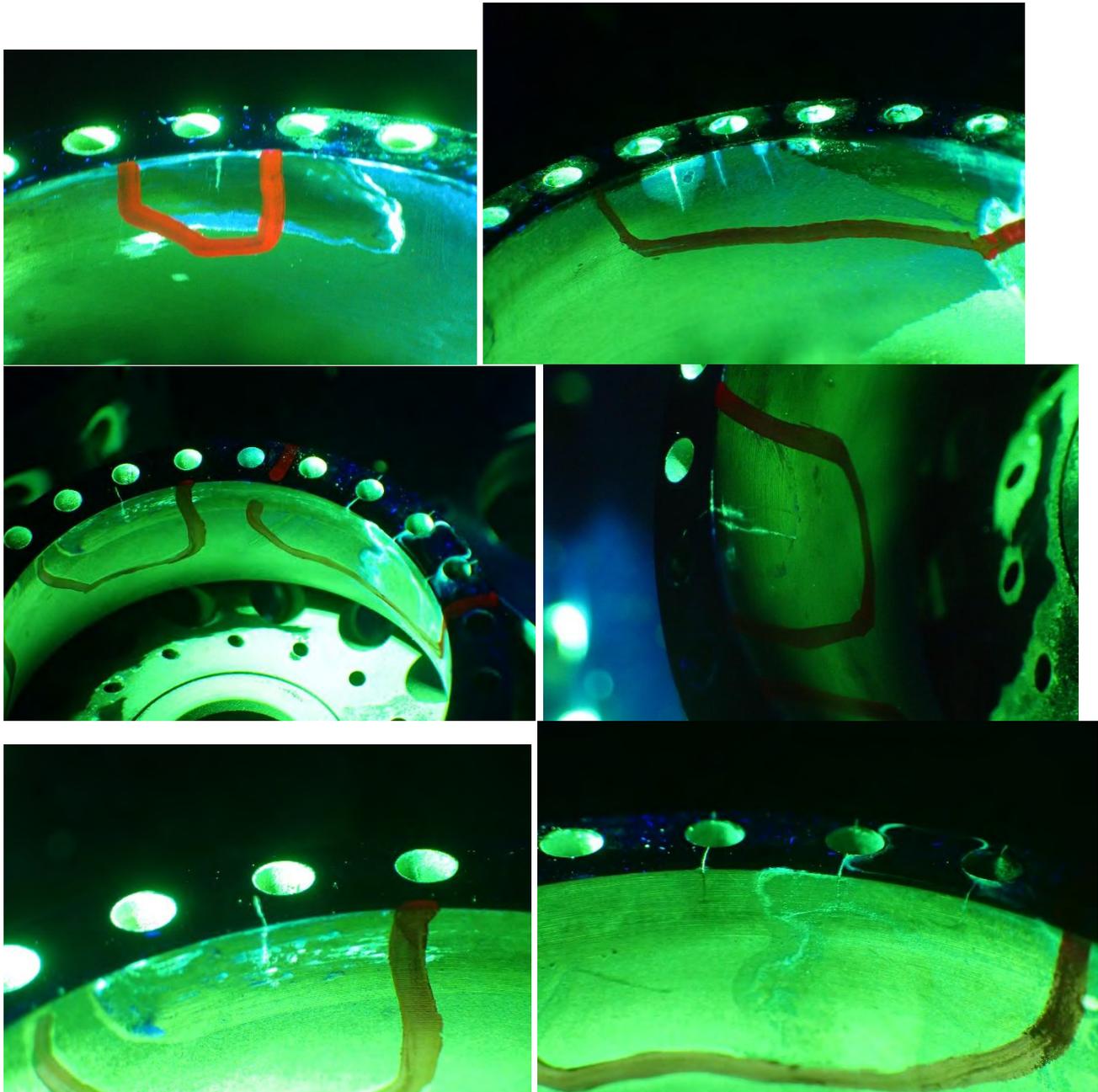
- **Metal oxidation and coating degradation** weakened the protective layer, exposing the base material to thermal stress and oxidation-assisted crack growth.
- **Structural stress concentration** at the outlet hole perimeters — a known weak point in the swirler geometry — contributed to the initiation and propagation of circumferential cracks under cyclic loading.

Conclusion:

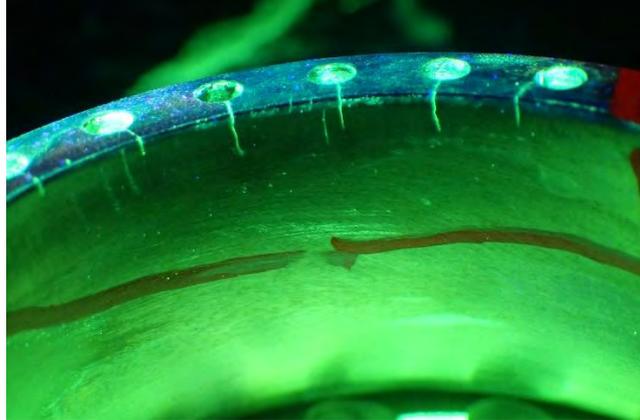
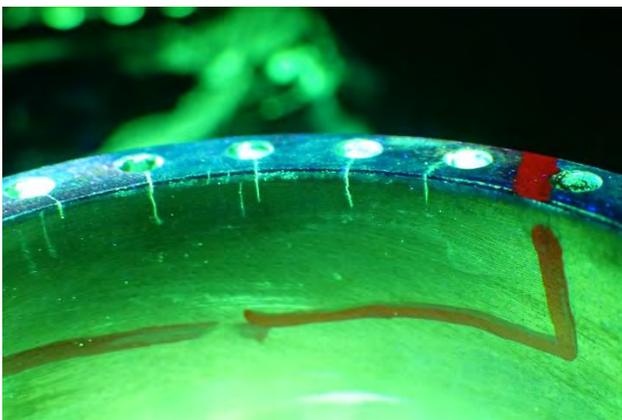
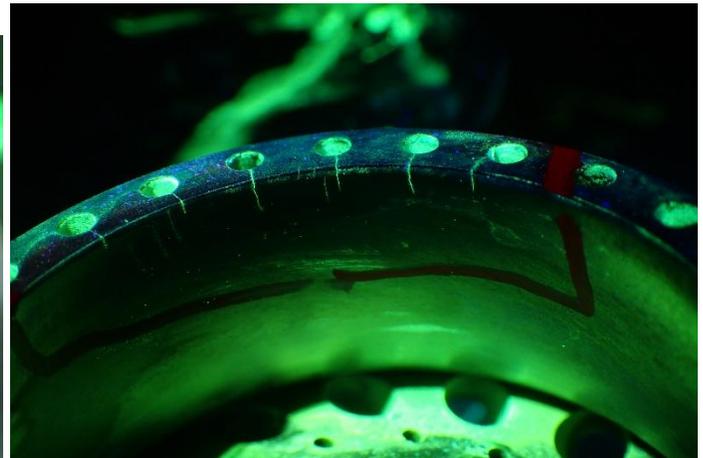
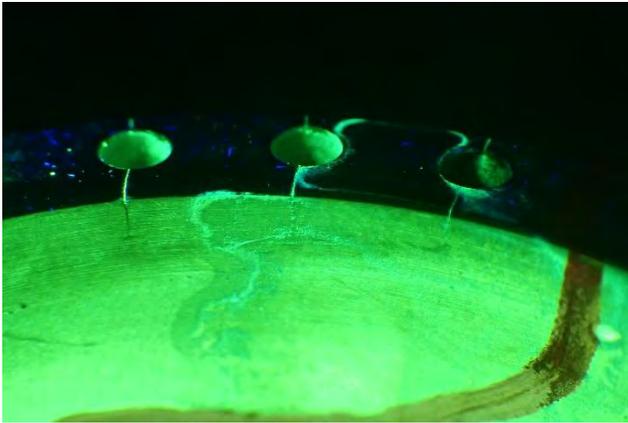
The 24 End Cover Gas Swirlers were assessed to be beyond refurbishable condition due to the presence of multiple thermal fatigue cracks and oxidation damage in critical flow zones. Continued operation in this condition would risk loss of mixing uniformity and potential combustion instability. All affected swirlers were therefore replaced under the heavy repair scope to restore the original flow distribution, mechanical integrity, and reliable mixing performance consistent with OEM standards.



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f. 16 x Water Pipes were found to be deformed

During inspection, **sixteen (16) Water Pipes** were found to be **deformed and out of dimensional tolerance**. The deformation was primarily observed along the curved sections and connection ends, resulting in misalignment and restricted flow passages.

Root Cause / Technical Explanation:

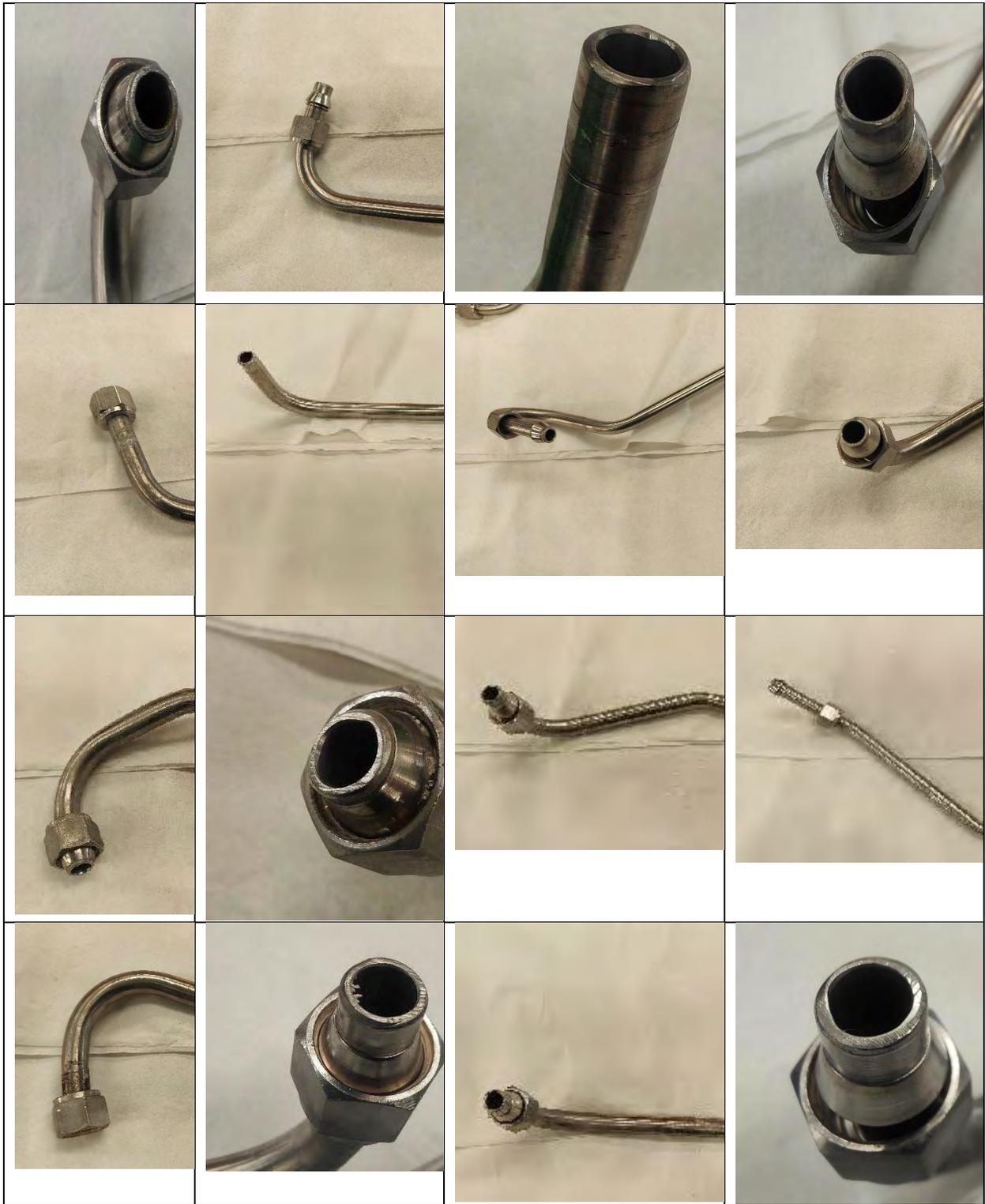
- **Prolonged exposure to high operating temperatures** led to gradual softening of the pipe material and thermal distortion, particularly in sections located near the combustion zone.
- **Thermal expansion and contraction cycles** during frequent start-up and shutdown operations induced mechanical stresses, causing gradual bending and ovalization of the pipe walls.
- **Vibration and pulsation from high-velocity water flow** contributed to material fatigue and structural displacement at unsupported segments.
- **Assembly stress during previous installations**—including over-tightened fittings and forced alignment—may have introduced residual strain, which amplified deformation over subsequent operation cycles.
- **Surface oxidation and scaling** reduced wall strength, making the pipes more susceptible to deformation under high thermal and pressure conditions.

Conclusion:

The 16 Water Pipes were determined to be beyond acceptable service limits due to deformation, wall thinning, and loss of alignment caused by thermal distortion, vibration, and material fatigue. The deformed geometry adversely affected water flow uniformity and cooling effectiveness. All affected Water Pipes were replaced under the heavy repair scope to restore correct alignment, flow capacity, and cooling performance in accordance with OEM-equivalent specifications.



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5. Damage Assessment Summary

5.1. Inspection Findings

During the incoming inspection, we observed that the components of the fuel nozzles were damaged far beyond the normal level expected for one operating cycle. Several critical components, including the End Cover Liner Pins, Liquid Cartridge Assemblies, Liquid and Water Cartridge Tips, Gas Swirlers, and Water Pipework, showed abnormal wear, erosion, cracking, and surface distortion.

5.2. Probable Root Causes

- High combustion temperature variations and unstable flame dynamics during operation.
- Frequent load changes and fuel transitions between gas and liquid modes.
- Unbalanced fuel and water flow distribution among nozzles.
- Fuel contamination and inadequate filtration resulting in erosion and coking.
- Inconsistent water quality, leading to corrosion, scaling, and tip damage.

5.3. Technical Remarks

We understand that this is the first refurbishment for this particular set of fuel nozzles since the unit was placed in service. As a result, the accumulated operating hours, exposure to high firing temperatures, and combustion environment have caused more severe degradation than normally expected in subsequent repair cycles.

The damage condition indicates that several components may require heavy repair or replacement to restore proper mechanical and flow integrity.

5.4. Recommendations

- a) Review and optimize fuel and water injection parameters to minimize thermal cycling and combustion instability.
- b) Improve filtration systems for both fuel and water to control contamination and particulate ingress.
- c) Verify purge air supply pressure and flow to ensure proper nozzle cooling and carbon prevention during shutdowns.
- d) Conduct water chemistry analysis and maintain water quality within OEM specifications.
- e) Review combustion tuning and DLN control to reduce dynamic pressure fluctuations.

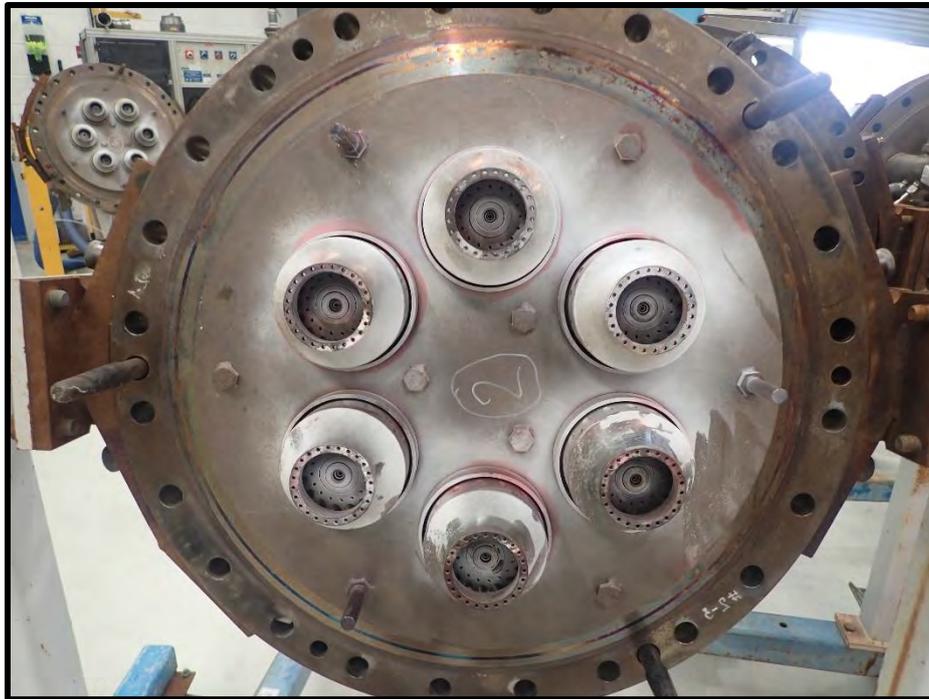
6. Conclusion

The GE Frame 6FA MNQC Syngas Dual Fuel Nozzles have undergone a complete as-received flow test, chemical cleaning, visual and dimensional inspections, and comprehensive non-destructive testing (NDT). The evaluation confirmed significant wear, thermal distress, and material degradation across multiple flow paths and sealing interfaces.

To restore these nozzles to full serviceable condition, the corrective actions outlined in Section 4 of this report must be carried out. These actions include part replacements, precision machining, weld restoration of eroded surfaces, dimensional recovery, and application of advanced protective coatings (MCrAlY and ceramic thermal barrier layers) to ensure long-term performance under high-temperature syngas and dual-fuel operating environments.

Upon completion of the recommended heavy repairs and re-certification testing, the nozzles will meet all OEM flow, dimensional, and material integrity requirements, ensuring reliability and optimized combustion performance for the next operational cycle.

7. Appendix A – As-Received Photographs



Nozzle Received (Hot side) with Evidence of DPI



Nozzle Received (Cold Side)

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