RELIABILITY REPORT

Title: Reliability Study on a Reformer
Author: SOIL Ingeniería

1. Summary

This report reviews the historical information of catalyst tubes, risers, and outlet manifolds of a MWK Reformer, the current condition, results from certain field tests, and operational recommendations.

Historical and design information was used to estimate the remaining life of the reformer harps. Data obtained from operating parameters allowed conclusions to be drawn on operational recommendations to be implemented, subject to review by Production and Process departments.

It is concluded that the weakest element in the assembly is the outlet manifold, which must operate at temperatures not exceeding 880°C, with occasional peaks up to 890°C. The combination of high temperatures and high heating/cooling rates leads to premature failures in furnace materials.

The South section of the reformer is operating with less air than the North section, resulting in higher manifold temperatures on the South side when fluctuations occur in the arch burner firing.

Tests conducted with individual burners showed that air regulation affects outlet manifold temperatures, lowering them.

In discussions with KBR representatives, it was confirmed that the gas temperature in the manifold is considered the same as the metal temperature of the manifold.

Temperature increases above 890°C with heating rates of 118.4°C/hr have been detected, with high potential to cause material damage.

It is recommended to take measures to avoid undesired damage. The air distribution in the reformer or the number of burners in service should be reviewed to implement a strategy ensuring operational temperatures and variations that enable the highest efficiency and reliability of the equipment.

2. Equipment or System Information

Steam Methane Reformer (MW Kellogg)

Part	Number	Fluid	Design Press. (Kg/cm^2)	Max. Op. Temp. (°C)	Material	Nominal thickness (mm)	OD (mm)	Op. Press. (Kg/cm^2)	Code	Hoop Stress (MPa)	Larson Miller
Catalyst Tubes	936	Gas, Steam, Reformed Gas	18	952	HP Micro (H39WM)	10.7 (MSW)	122.9	17,41	API 530	9.25	35.45
Risers	18	Gas reformado	18	980	HP Micro (H39WM)	14 (MSW)	158	17,41	API 530	9.08	35.55
Outlet Manifold	18	Gas reformado	18	890	A351 CT15C (CR32W)	18	203	17,41	API 530	9.07	26.30

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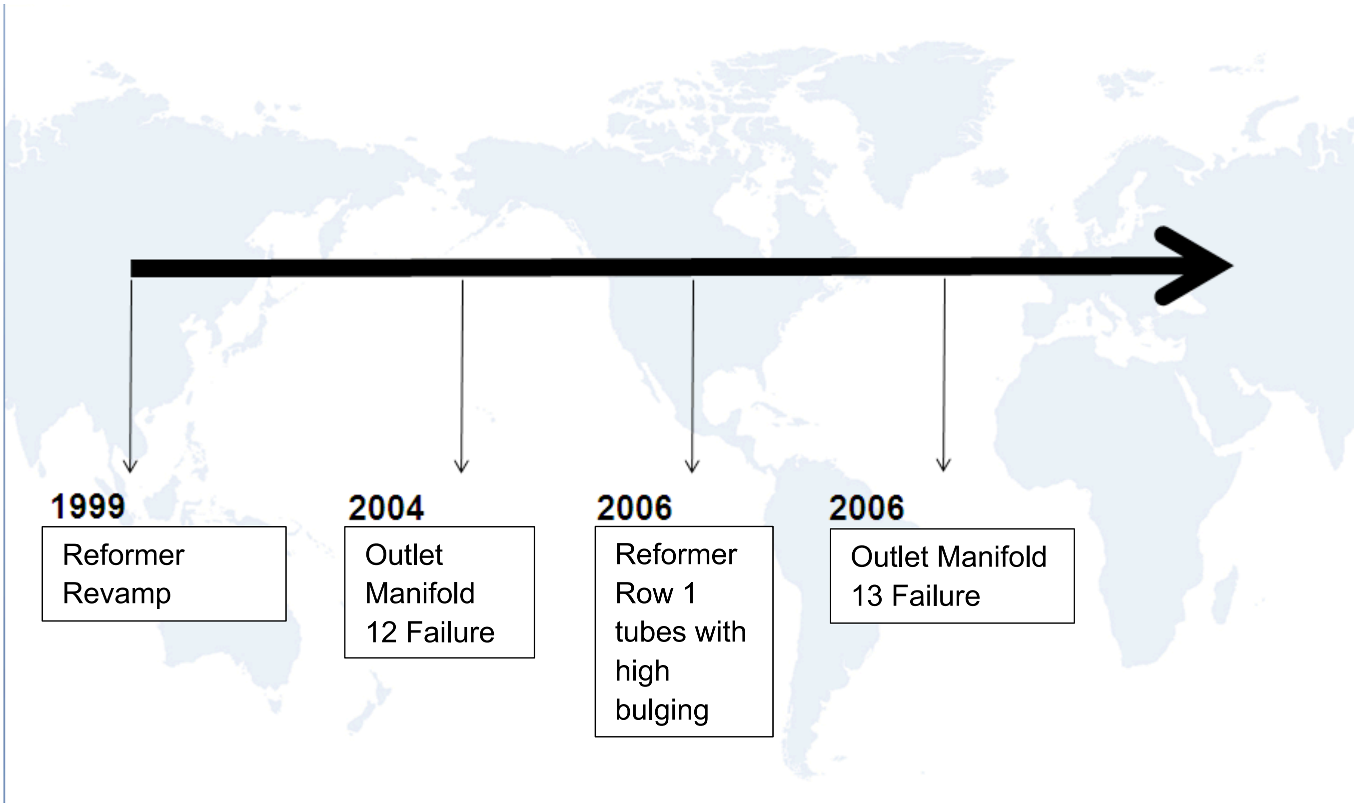
All design parameters comply with a 100,000-hour service life. As discussed with KBR, the wall temperature of the outlet manifold is assumed to be the same as the gas temperature inside it.

3. Description of Events and History

Post-1999 revamp: Three significant events have occurred in the reformer.



Manifold 12 failure (2004): Several severe cracks were found, mainly around the weld between the manifold and the weldolet, propagating toward adjacent weldolets. Collateral damage occurred to tubes 35–39, with lesser cracking on tubes 40–45. Repair consisted of replacing only the damaged section, which remains in service. Failure analysis attributed the cause to creep cracking from stress relief of high residual stresses due to welding.

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2006 Turnaround: LOTIS inspection found seven tubes exceeding 3% expansion (removal criterion), with microstructural analysis indicating prolonged exposure to high temperatures. Tube 2/41 showed complete disappearance of secondary carbides; temperature ranking based on carbide density: T2/41 > T10/38 > T10/37 > T11/52.

- Row 2 tube 41, 17.95%
- Row 10 tube 35, 3.12%
- Row 10 tube 36, 3.20%
- Row 10 tube 37, 3.25%
- Row 10 tube 38, 15.96%
- Row 13 tube 52, 3.36%
- Row 11 tube 52, 5.43%
- Riser 6 bulging close to 3% (2,92%)

Manifold 13 failure (2006): Occurred during plant restart. Analysis showed end-of-life creep failure due to combined temperature, pressure, and material strength factors. Microstructure was as expected but showed aging from high-temperature exposure.

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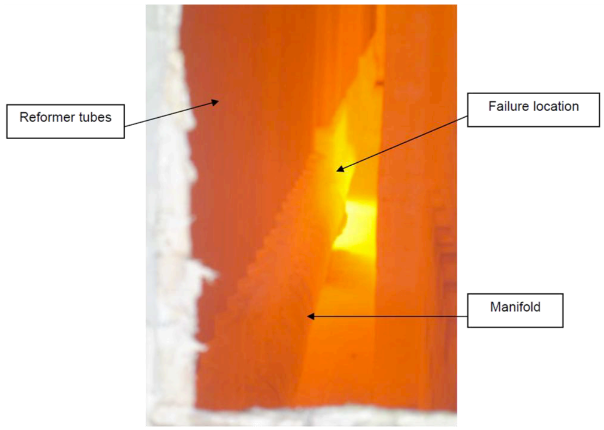

4. Study

The manifold 13 failure was caused by high temperature, as was the case for tube expansions. Manifold 12's failure is likely linked to fabrication defects and possibly spring misadjustment rather than temperature. It is possible other manifolds have defects and have experienced high-temperature operation.

Post-2006, operational temperatures have been higher and unevenly distributed. The TSI 21512812 set new high and high-high alarms for manifolds and TR110A/B. After September 2013 startup, the previously observed air distribution imbalance (higher temperatures South, lower North) reappeared, and some load changes exceeded TSI alarm limits.

Given the manifolds' 69,000 service hours and past failures, an operational strategy must be implemented to ensure reliability without affecting plant efficiency.

5. Historical Data Review

Analysis of 2004–2006 operation (FER near 100%) shows high temperature "upsets," significant temperature deltas, and oscillations. In 2006, deltas ≥100°C were frequent. Maximum temperatures in all three years reviewed could cause premature manifold failure, especially with oscillations.

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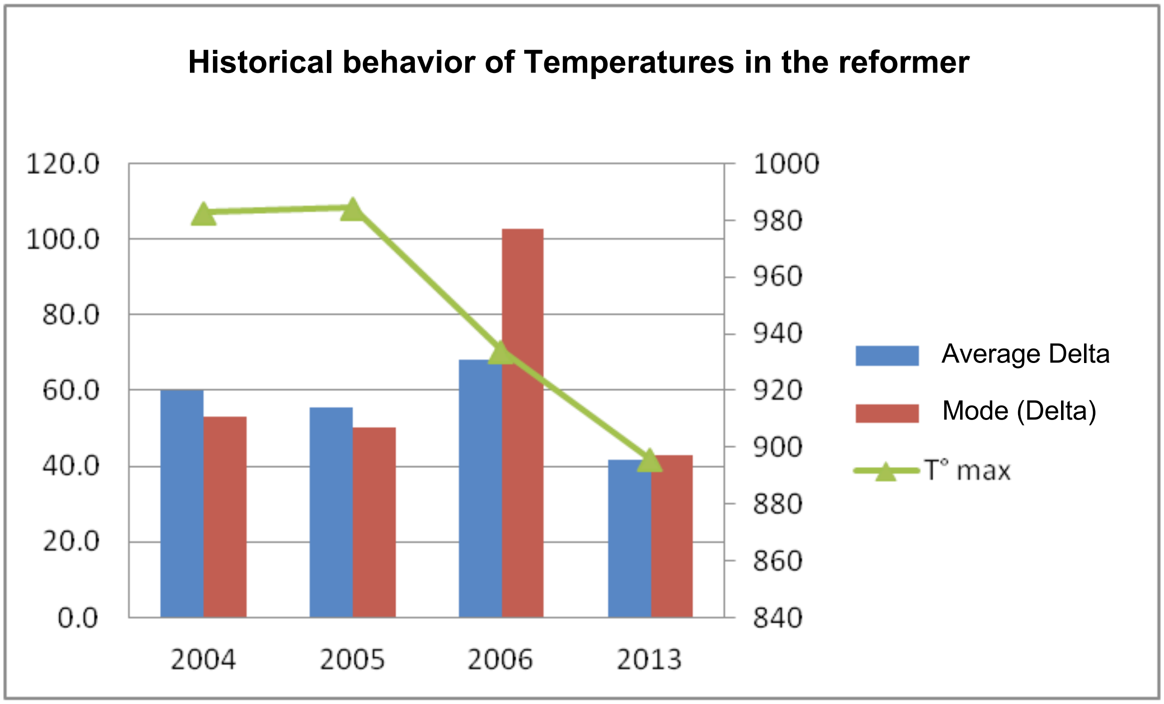


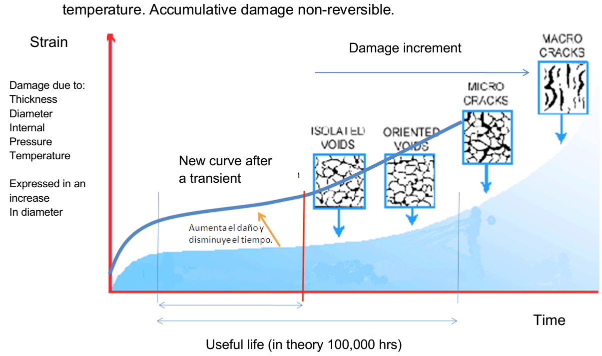
6. Thermal Cycling Effects

High temperatures reduce material properties, shortening service life. Rapid heating/cooling cycles accelerate damage. Thermal stresses during heating can reach four to five times the yield strength at service temperature if expansion/contraction is restricted. Damage relief occurs via creep; pre-existing creep damage leads to cracking or failure.

Creep Damage Theory

Steady State: Temperature and Pressure constant. Damage Rate constant

Transients: Changes in Temperature and/or Pressure not constant. Damage accelerated. Curve moves up. Magnitude depends on time and the changes in temperature. Accumulative damage non-reversible.



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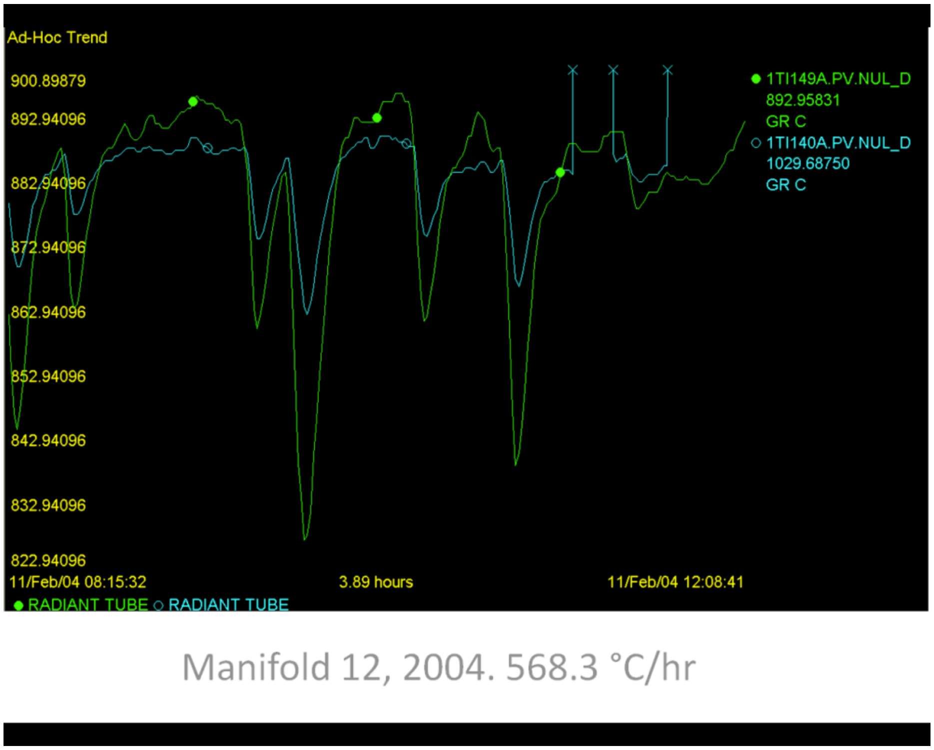
Examples from 2004 and 2006 showed extremely high cooling rates (568.3°C/hr and 573.5°C/hr).



Manifold 12, 2004. 568.3 °C/hr

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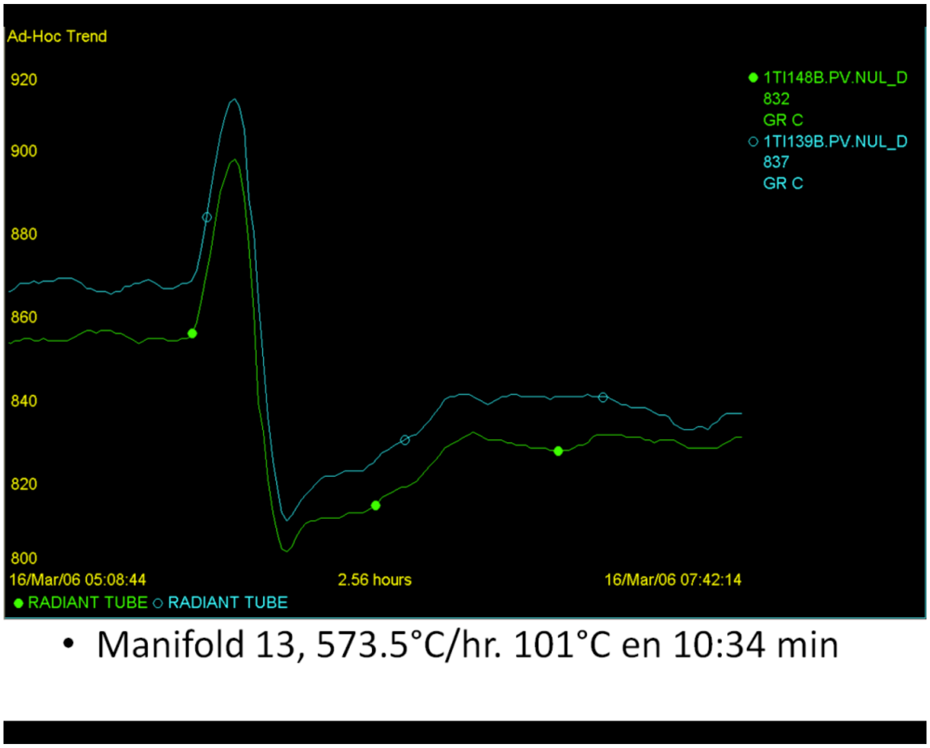

7. 2013 Situation

Lower load operation is less severe, but damage is cumulative. Current air imbalance affects manifolds 3, 17, 13, and 15 most. Manifold 13's 2006 repair was partial; remaining sections were exposed to earlier severe conditions. Furnace temperatures have reached 895.5°C (max) and averaged 875.5°C, with some exceeding TSI alarm limits. Heating/cooling rates above the 50°C/hr criterion have also occurred.

Air adjustments on burners for rows 3 and 17 reduced temperatures to acceptable levels. Risers and tubes, made from more creep-resistant, ductile materials, operate well below maximum limits, but high temperatures should still be avoided to preserve life.

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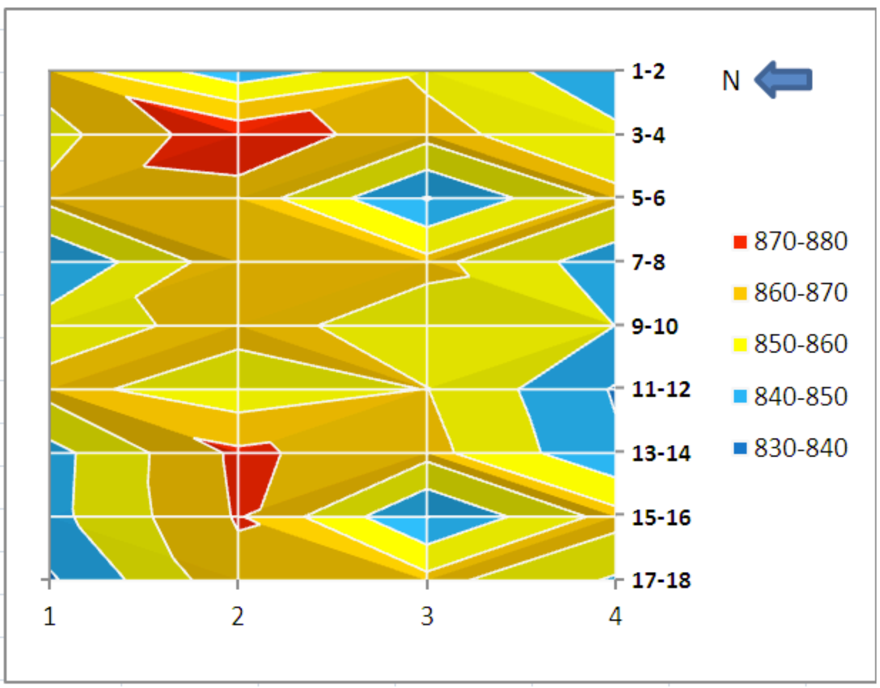
Pressure in mmH₂O	South/North	Pressure in mmH₂O
5	A	10.1
3.1	B	10.7
3.8	C	10.2
4.1	D	9.9
5.9	E	9.9
4.2	F	10.3
4.3	G	10.6
3.3	H	11.2
3.9	I	11.5
4.4	J	9.8

As a result, an uneven temperature distribution can be seen, with the greatest impact on manifolds 3, 17, 13, and 15. The distribution for November 22, 2013 is shown as an example:



The repair carried out on manifold 13 in 2006 was partial, so sections that were subjected to the conditions seen between 2004 and 2006 remain. Furthermore, the furnace has been operating at temperatures reaching a maximum of 895.5°C and an average of 875.5°C. These values are not excessively high, but the maximum temperature has exceeded the alarm specified:

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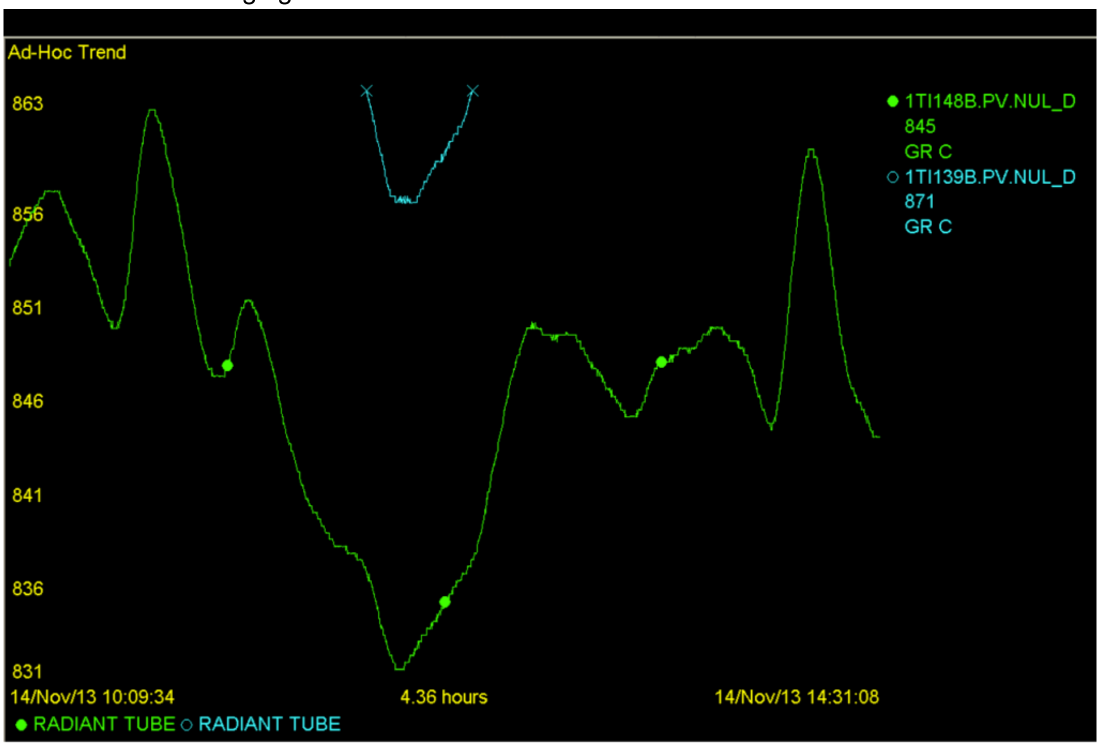
Thermocouple	*High*	*High-High*	*Low*	*Low-Low*
Manifold TI-137 al TI-154 A/B	880	885	800	N/A
Process TR-110 A/B	N/A	890	N/A	0
Process T-AVG A/B	N/A	870	N/A	0

Regarding heating and cooling rates, there have also been cases where these have exceeded the 50°C/hr threshold. This can be seen in the following figures:



70 °C/hr

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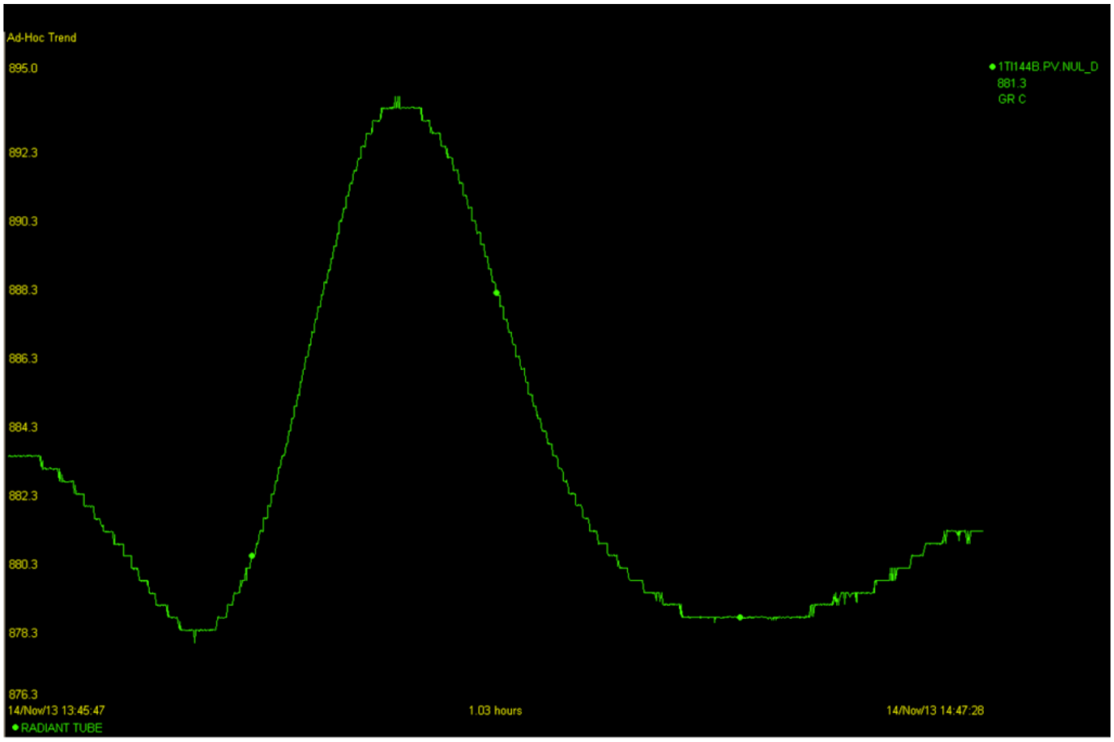

118.4 °C/hr

Adjustments Made

In conjunction with Production personnel, an adjustment was made to the burners associated with rows 3 and 17, increasing the air flow, thereby achieving a temperature reduction to an acceptable level.

The adjusted burners were:
I-20, I-22, I-24 row 3
A-21, B-25, B-26 row 17

Risers and Tubes

While they are subject to the same variations and operating conditions as the arc burners, these parts are made of a different material that is more resistant to creep and has a more ductile aging behavior and less loss of strength. The operating temperatures measured with a pyrometer show that these are far from the maximum allowable temperatures, as shown in the following figures:

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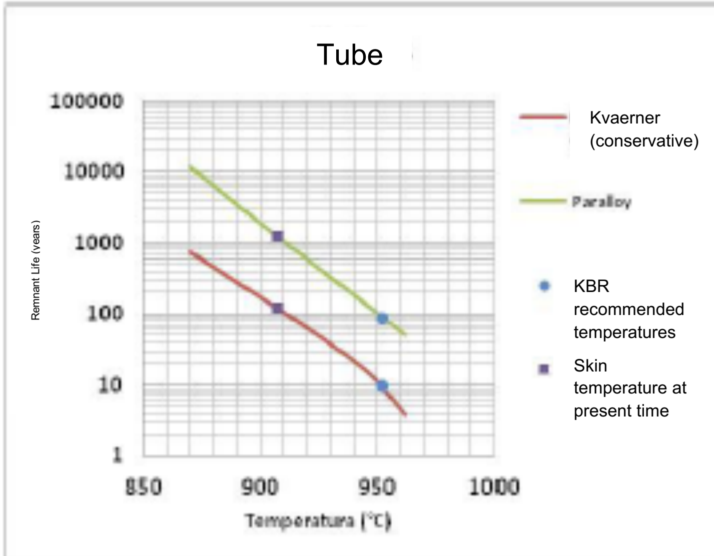

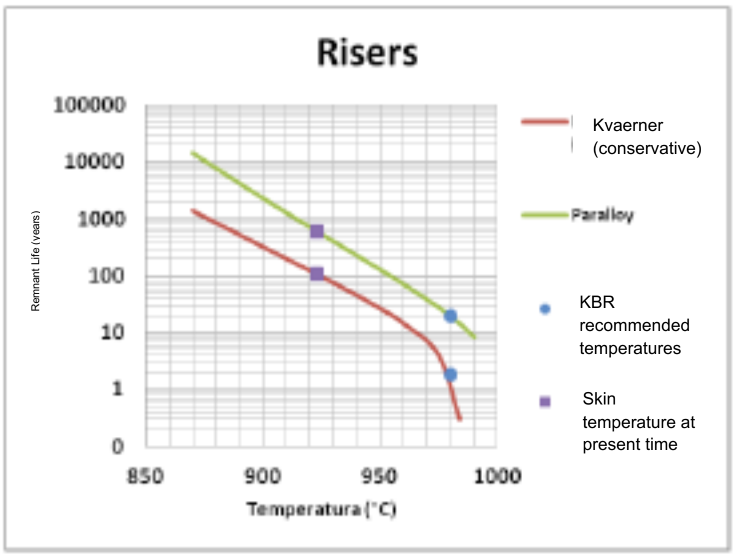

Although these are theoretical curves, it can be seen that the operating temperatures are far from causing significant damage to the materials. However, care must be taken to avoid high temperatures, as these also affect the remaining life of the material.

8. Conclusions

1. High temperatures contributed to the 2006 manifold 13 failure; all furnace materials suffer damage above alarm thresholds.
2. Gas temperature in manifolds equals metal temperature.
3. Furnace shows both excessive temperatures and oscillations that can accelerate damage.
4. Temperature control is essential for reliable operation.
5. Tubes and risers are less affected if temperatures stay below maximum limits.

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6. Recommended actions:
- Balance air distribution to arc burners to lower South-side temperatures.
- Make local air adjustments to arc burners as needed.
- Keep manifold operation within established alarms; avoid exceeding them.
- If temperature control is insufficient, consider shutting down some burners during low-load operation.
- Monitor temperature change rates, keeping them below 50°C/hr.

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