Firetube Failure Analysis and Operating Guidance

1. Executive Summary

A recent firetube failure was evaluated and determined to be consistent with over-firing and operation beyond the thermal design limits of the firetube, rather than a material or manufacturing defect. Evidence indicates the firetube metal experienced excessive temperatures, resulting in softening, loss of structural integrity, and collapse under normal operating pressure.

This document outlines:

- Metallurgical temperature limits of common firetube materials
- API-referenced operating considerations
- Heat transfer limitations in heater treaters
- Process-specific considerations for crude oil and produced water systems
- Recommended operating practices to prevent recurrence

2. Material Temperature Limits

2.1 ASTM A36 Carbon Steel

ASTM A36 is a structural carbon steel commonly used in lower-temperature applications.

- Recommended maximum continuous service temperature: ~750°F (400°C)
- Significant strength degradation begins: ~800°F (427°C)
- Rapid loss of yield strength and creep resistance: >900°F (482°C)
- Oxidation and scaling accelerate significantly above 800°F

At elevated temperatures, A36 steel experiences:

- Reduction in yield strength
- Increased creep deformation under stress
- Accelerated oxidation and scaling

2.2 ASTM A516 Grade 70 (Pressure Vessel Steel)

A516-70 is commonly used in pressure-containing equipment, including firetubes.

- Recommended maximum continuous service temperature: ~800°F (427°C)
- Strength degradation becomes significant: ~850–900°F (454–482°C)
- Creep and metallurgical instability: >900°F

While A516-70 performs better than A36 at elevated temperatures, it is still subject to:

- Creep deformation
- Oxidation and sulfidation
- Loss of mechanical strength under sustained overheating

2.3 Failure Mechanism Observed

The observed collapse of the firetube is consistent with:

- Over-temperature exposure beyond material limits
- Metal softening due to elevated temperature
- External pressure exceeding reduced strength capacity

This failure mode is characteristic of over-firing conditions.

3. API Guidance and Heat Flux Considerations

API Recommended Practices for fired vessels and heater treaters emphasize:

- Maintaining operation within design heat flux limits
- Avoiding localized flame impingement
- Proper burner management system (BMS) control of temperature

Exceeding heat flux limits leads to:

- Elevated metal temperatures beyond allowable limits
- Thermal stress and creep
- Accelerated oxidation and sulfidation

As outlined in API recommended practices for fired equipment (e.g., API RP 556 and API RP 535):

- Tube wall temperature rises disproportionately when heat flux limits are exceeded
- Oxidation, creep, and fatigue mechanisms accelerate significantly

4. Heat Transfer Limitations in Heater Treaters

4.1 Fundamental Limitation

Firetube systems are limited not by burner capacity alone, but by the ability of the process fluid to absorb heat.

When heat input exceeds the rate at which heat can be transferred away:

- Metal temperatures increase rapidly
- Localized hot spots develop
- Firetube failure risk increases significantly

4.2 Produced Water vs. Crude Oil Heating

Produced Water (Salt Water Phase)

- Higher specific heat capacity
- Requires more energy for temperature increase
- Often continuously removed from the vessel

Implications:

- Heat input may not result in expected temperature rise
- Operators may increase firing rate to compensate
- Leads to overheating of firetube metal

Crude Oil Heating (Recommended Control Basis)

- Lower specific heat compared to water
- More stable temperature measurement basis
- Better representation of vessel temperature

Recommendation:

- Temperature control should be based on crude oil phase, not water phase

5. Effects of Light Hydrocarbon Components (Bakken Crude)

Bakken crude contains significant fractions of:

- Propane
- Butane
- Pentane

These components have:

- Low boiling points
- High vapor pressures

5.1 Heat of Vaporization Losses

A large portion of heat input is consumed by:

- Vaporizing light hydrocarbons
- Energy leaving the vessel in the gas phase

Result:

- Reduced effective heating of bulk fluid
- Apparent cooling effect within the vessel
- Increased tendency to over-fire to compensate

5.2 Operational Impact

- Heat added does not fully translate to temperature rise
- Excess firing increases firetube metal temperature
- Elevated failure risk

6. Additional Contributing Factors

6.1 Burner and BMS Control

Potential issues include:

- Incorrect temperature set points
- Faulty temperature measurement location
- Malfunctioning BMS control systems

6.2 Fuel Gas Quality

High BTU gas and heavier hydrocarbons can cause:

- Hot spots
- Flame impingement
- Uneven combustion

As recognized in API guidance for fired heaters and burner operation (API RP 556):

- High BTU fuel gas and heavier hydrocarbons contribute to localized overheating, flame instability, and potential coking

7. Operating Recommendations

1. Temperature Control
    - Set temperature only to meet required conditioning specifications
    - Do not exceed target temperature unnecessarily
2. Measurement Location
    - Base control on crude oil temperature
    - Avoid using water phase as primary control variable
3. Burner Management
    - Verify BMS functionality and calibration
    - Ensure proper burner tuning
4. Fuel Gas Considerations
    - Account for BTU variability
    - Avoid conditions that promote flame impingement
5. Heat Input Management
    - Operate within design heat flux limits
    - Do not increase firing rate to compensate for process inefficiencies
6. Use of Lick Plate / Flame Shielding
    - Installation of a lick plate (flame shield) within the firetube can help prevent direct flame impingement on the pressure boundary
    - This provides a sacrificial surface to absorb localized high heat flux from the burner
    - Note: If the burner is over-fired, the addition of a lick plate will not eliminate failure risk—it will only relocate the failure point further down the firetube

8. Conclusion

The firetube failure is consistent with over-temperature operation caused by excessive heat input relative to the system's ability to absorb and dissipate that heat. Material limits for both A36 and A516-70 steels were exceeded, resulting in loss of strength and structural collapse.

Preventing recurrence requires:

- Operating strictly within temperature and heat flux limits
- Controlling based on crude oil temperature
- Accounting for vaporization losses in light hydrocarbon systems
- Maintaining proper burner and BMS operation

Temperature should be set only to meet required specifications and not exceeded, as additional heat input does not improve performance and significantly increases the risk of firetube failure.