Refractory Design Compatibility Study in SRU Thermal Reactors

Brimstone Sulfur Recovery Symposium Virtual Vail

Haytham A. Al-Barrak

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Outline

Background

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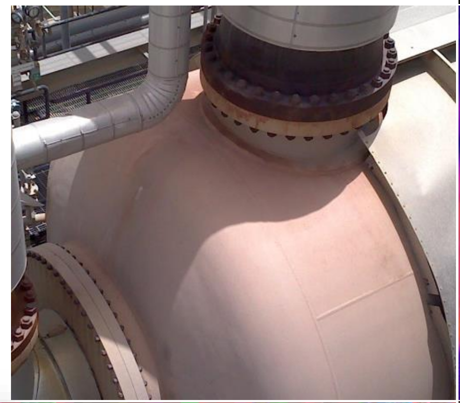
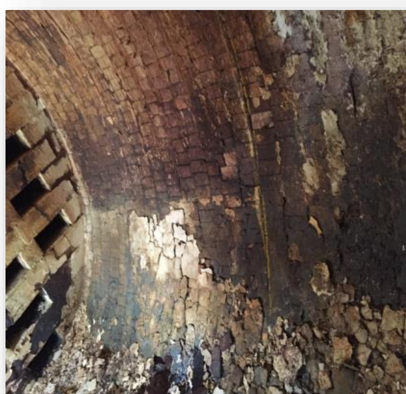
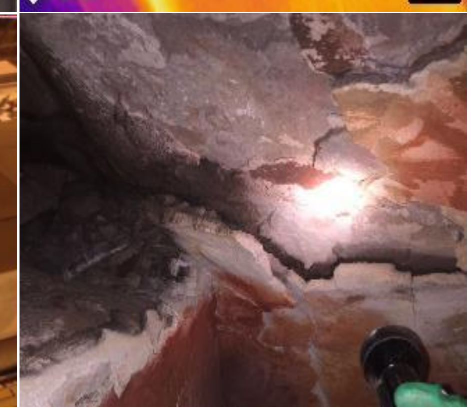
Background – Impact of refractory failures

- Unplanned shutdowns
- Extended downtime
- Limited throughput (hot spots)
- Safety hazards



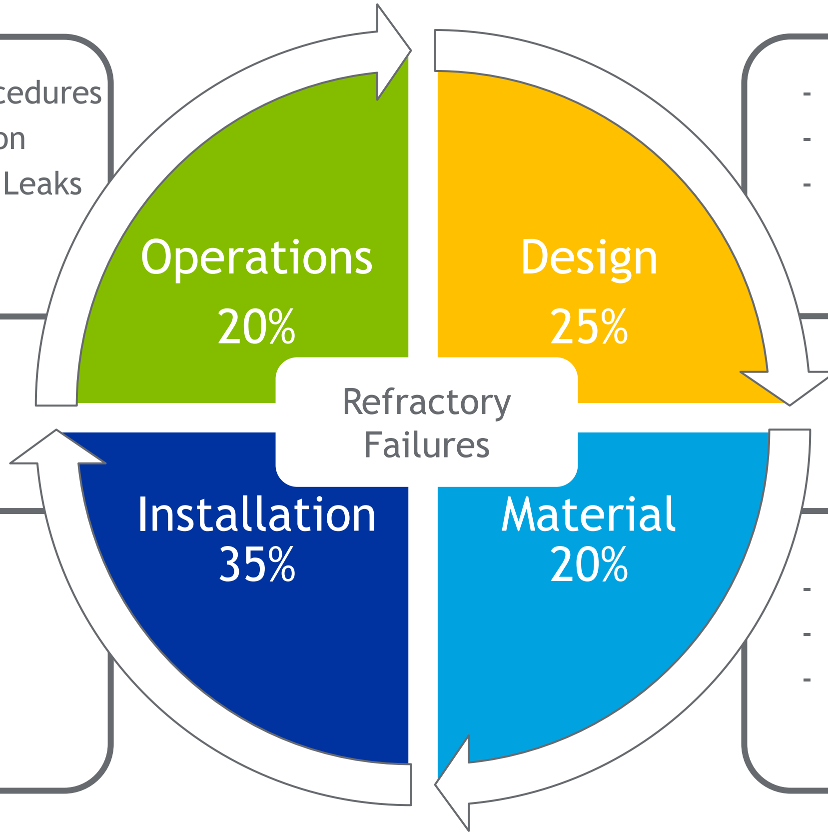




Background - Failure Categories

- Startup & Shutdown Procedures
- Control & Instrumentation
- Liquid Carryover & WHB Leaks

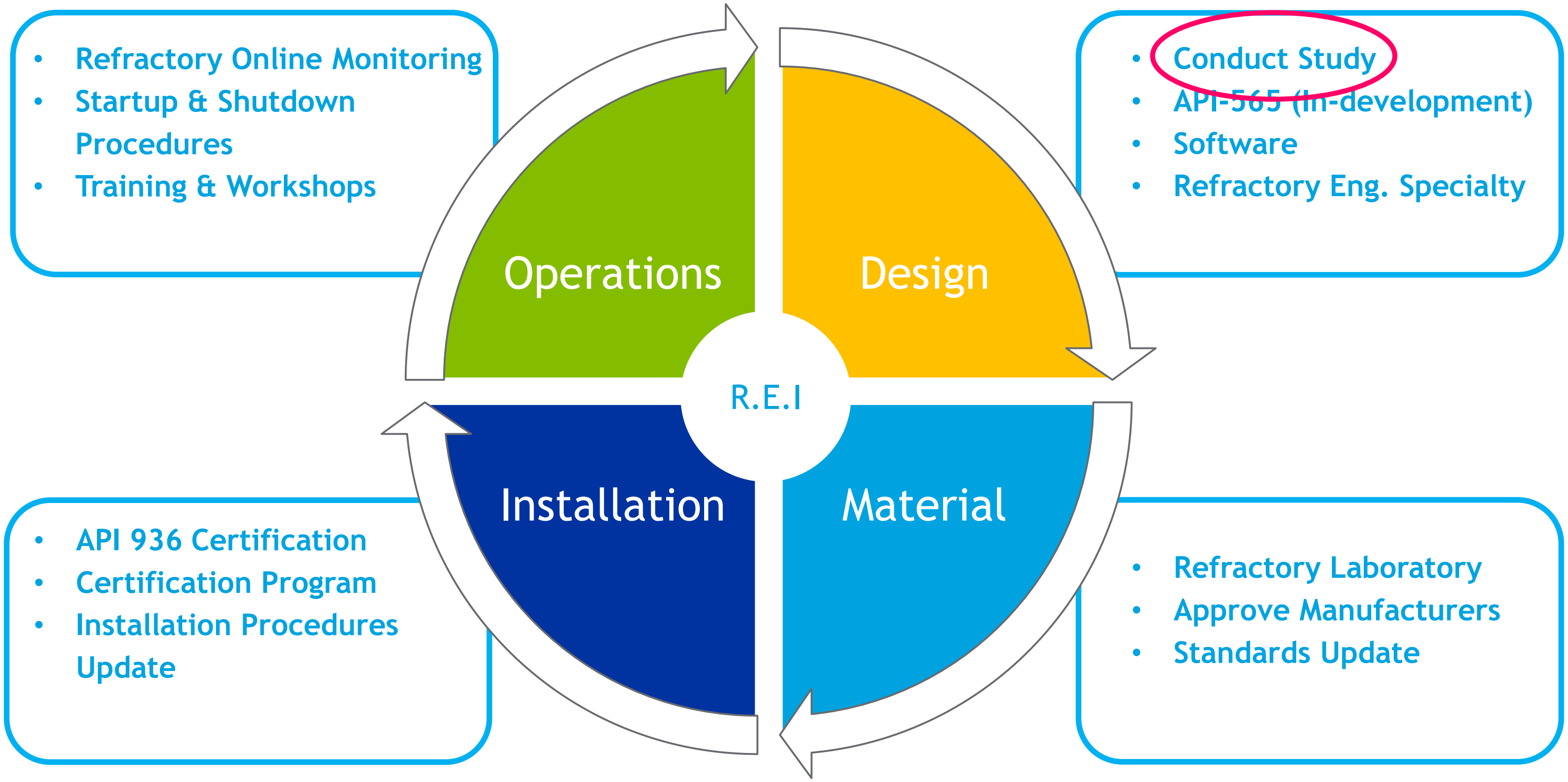
- Engineering
- Material Selection
- Burner & Equipment Design



- Installers Competency
- Installation Procedure
- Quality Control

- Manufacturing
- Testing
- Material Quality

Background – Refractory Enhancement Initiative



Objective

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Study - Objective

Conduct assessment on one Saudi Aramco problematic SRU Thermal Reactor:

- Evaluate refractory material compatibility
- Determine causes of failure(design, operation, materials, specifications, etc.)
- Provide recommendations
  - Address failure mode
  - Upgrade refractory lining system design and material
  - Optimize refractory life and reliability
    - 20 years with minimum repairs

Methodology

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Study – Methodology

I. Preparation
II. Review
III. Simulation

Preparation – Pre-Study

Team Assembly:

- End User – Saudi Aramco
- Refractory Consultant – Thorpe International Services, Inc
- SRU Process Consultant – Nasato Consulting LTD.
- CFD / Burner Consultant – HEC International Services, Inc

Equipment Selection:

- History of consistent repeated refractory failures
- Four (4) Identical SRU trains

Review

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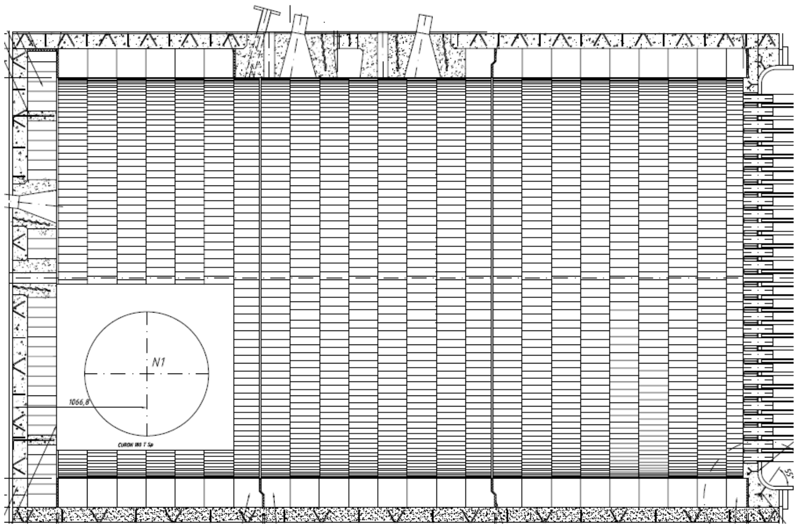
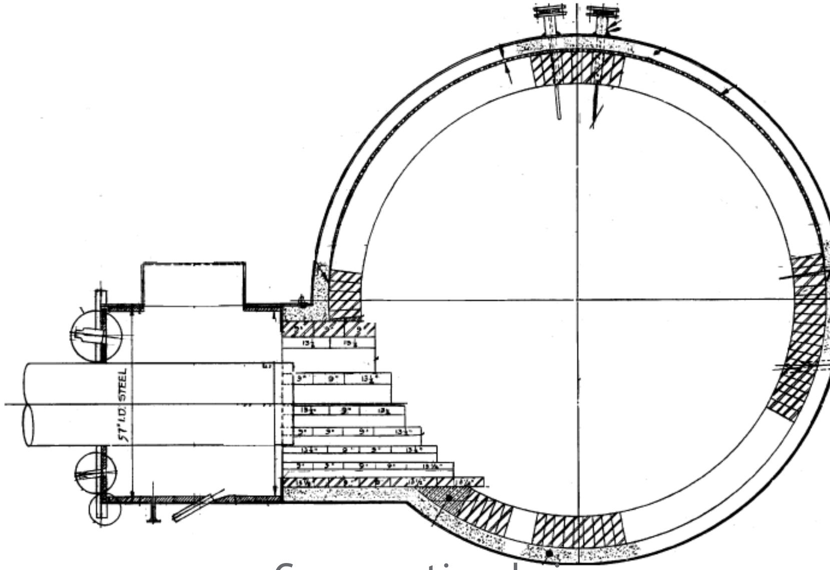
Review – Eqiupment

- Tangential fired Thermal Reactor commissioned in late 1970's
- Consistent and repeated refractory failures since commisioning
- Most failures around burner, upper part of cylinder & tubesheet.
- Most failures on WHB tube sheet protection system causing ferrule failure and ruptured/leaking tubes
- No internal mixer
- Furnace Dimensions 12'-9" ID and 20'-1/16" long
- End wall is flat steel plate.
- No weather shroud is used since commisioning



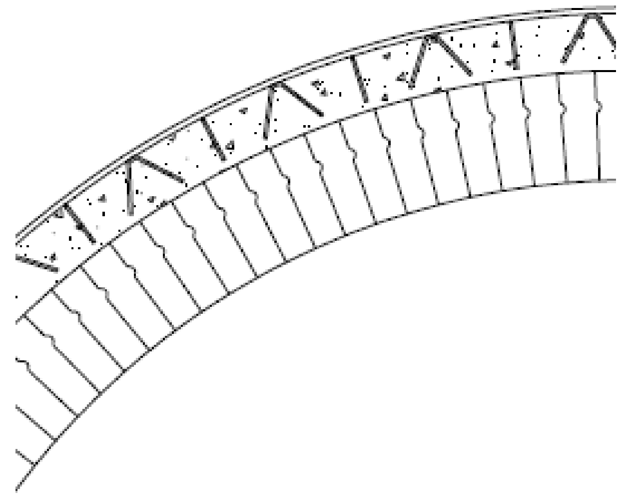
Side view



Cross sectional view

Review – Refractory System

- Lining is dual layer consists of:
  - 4.7” Insulating Castable with 310SS Anchors
  - 9” Hotface Brick
- Refractory was changed to new refractory material of in 2013, only material was upgraded while design is the same.



- Refractory Brick is 94% alumina, and uses tongue and grove (T&G) installation method.

- Nozzle consists of monolithic refractory with no backup insulation.

Review – Refractory Flatwall

Flat walls have issues due to the thermal gradient through brick lining. Since the hotface brick will pull towards the heat, the shell will be tightened by the refractory

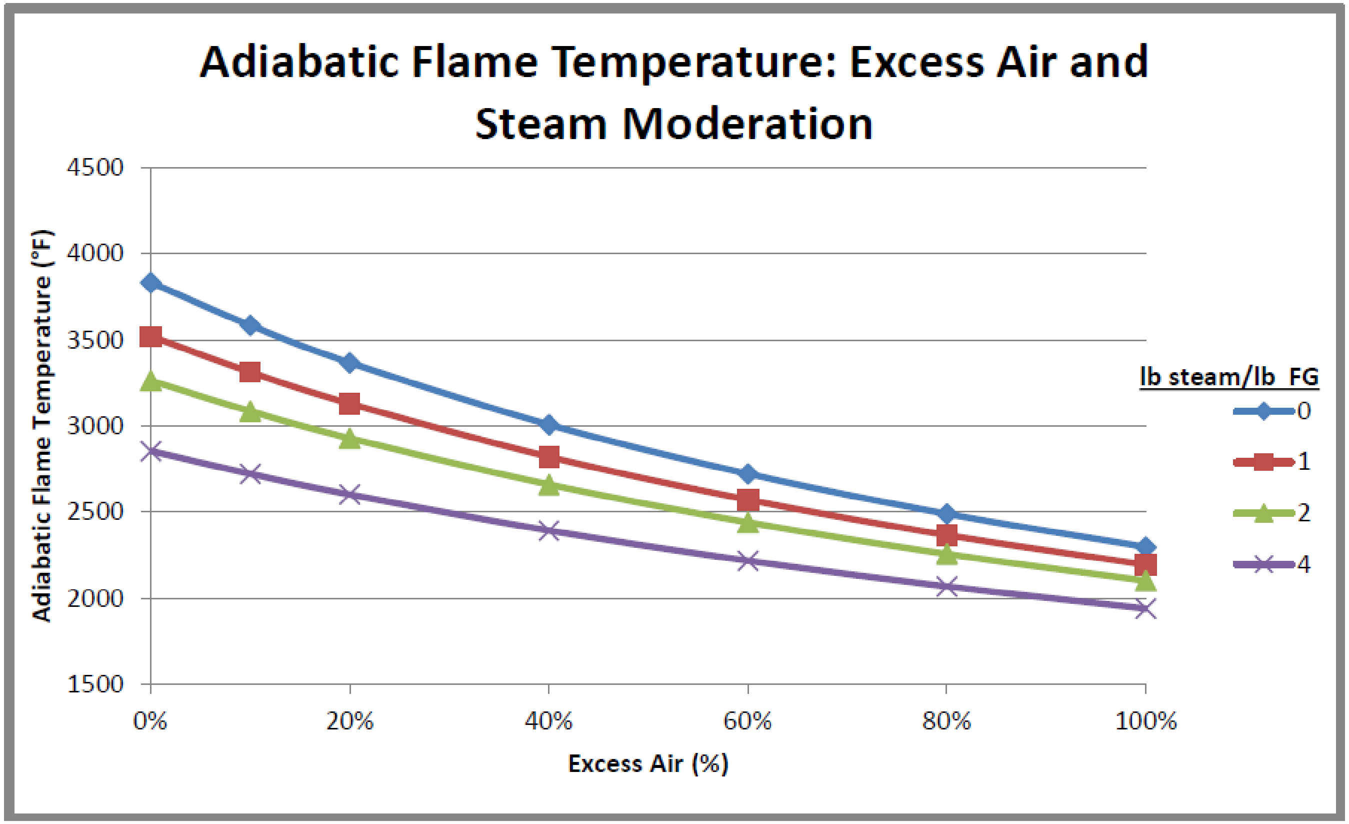
Refractory pulling away from the shell and towards the heat source, will allow for hotspots to form on the shell.

Tangential ring type burner

Flat wall on Thermal Oxidizer

Review – Process and Instrument

- Unit designed fuel gas for start-up, shutdown and hot standby.
- Resulting flame temperature of 3000+ °F can be damaging and thus fuel gas firing requires flame moderation.
- Fuel gas for this case study used is:
  - 80% Methane
  - 5% Ethane
  - 15% Propane



Review – Process Review

- Thermocouples at 3 o'clock position
- Equipment startup and shutdown procedure exclude any type of flame moderation for extended run times.
- At stoichiometric burn strategy, the refractory and burner components are exposed to temperatures of approximately 3800 °F for several hours and even possibly days.

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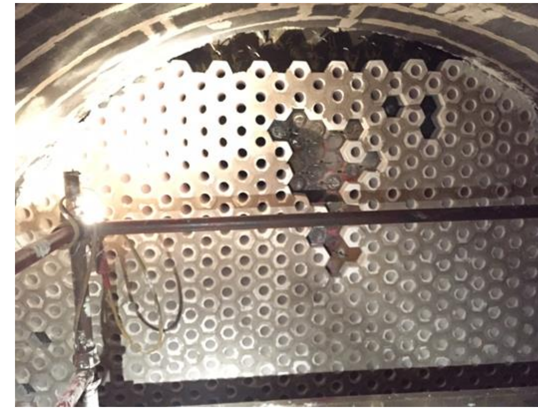
Review –Site Visit

Due to the unavailability of historic photos, interviews with Plant Personnel were held.

- Failures were more common near the tubesheet/ferrules

- Discolored refractory found after every T&I



Simulation

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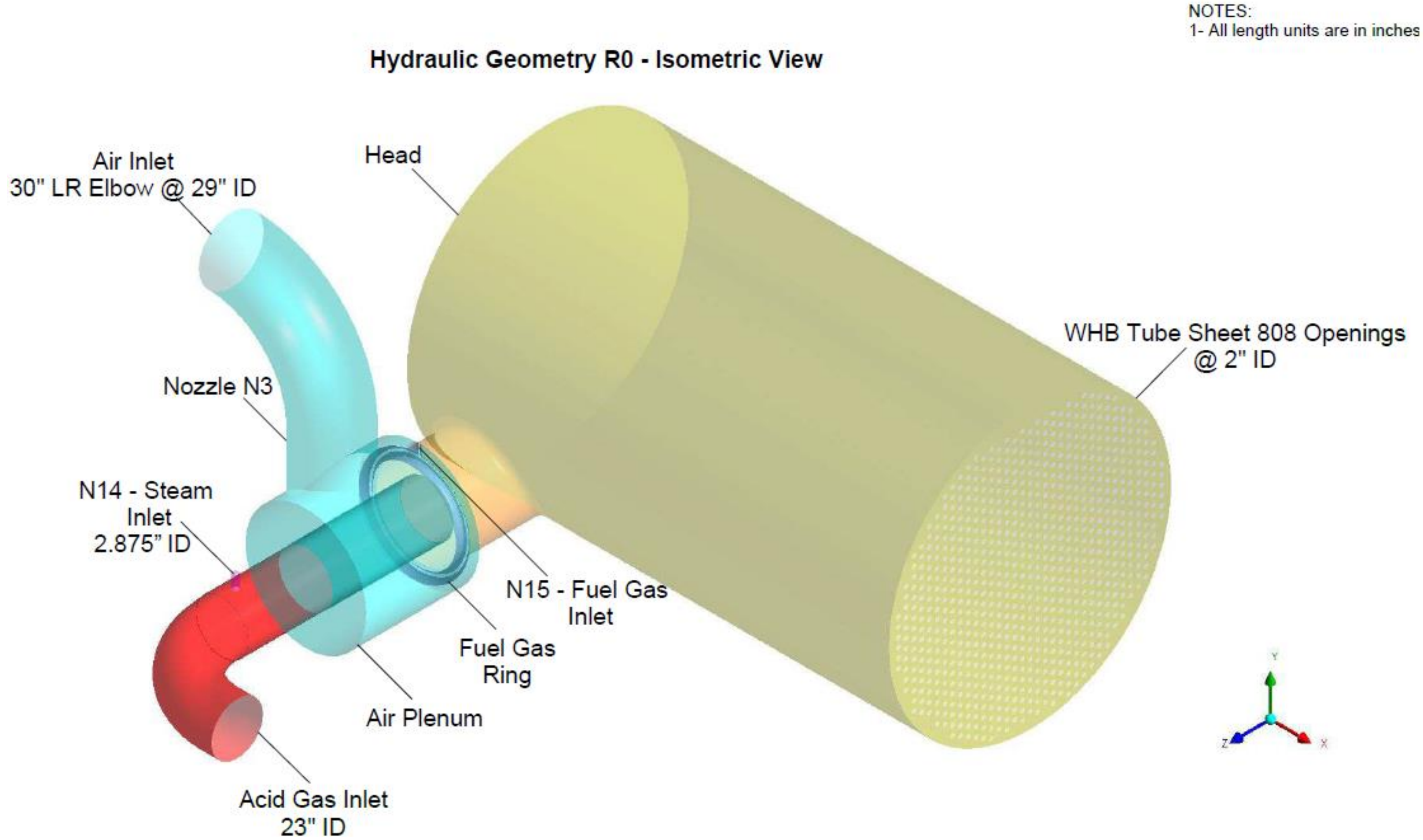
Simulation – Simulation Overview

- CFD software used is *ANSYS CFX-V17.2*

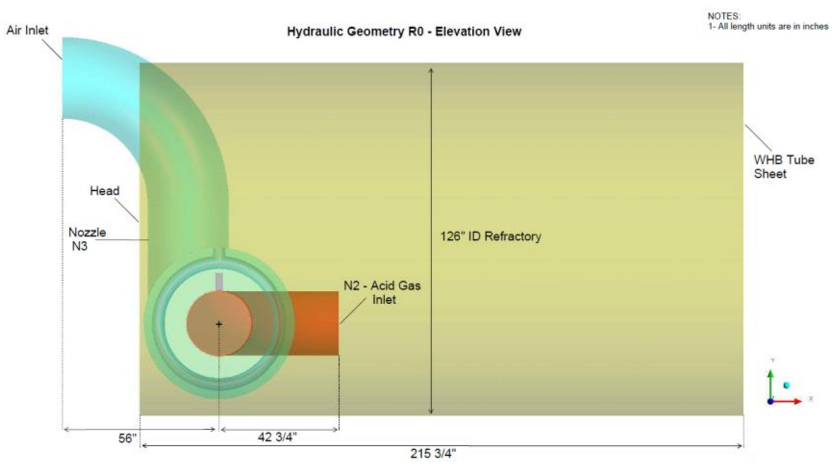
- CFD Parameters
- Chemical Reactions
- System Geometry – Hydraulic Domain
- Mass and Heat Transfer Boundary Conditions

- Other Assumptions:
  - Inlet air and acid gas velocities evenly distributed.
  - 1Dimension heat transfer heat loss through refractory, orthogonal to refractory surface.
  - Heat distribution by lateral conduction was not taken into account.
  - Gas buoyancy (gravity) effects were included on the simulation.

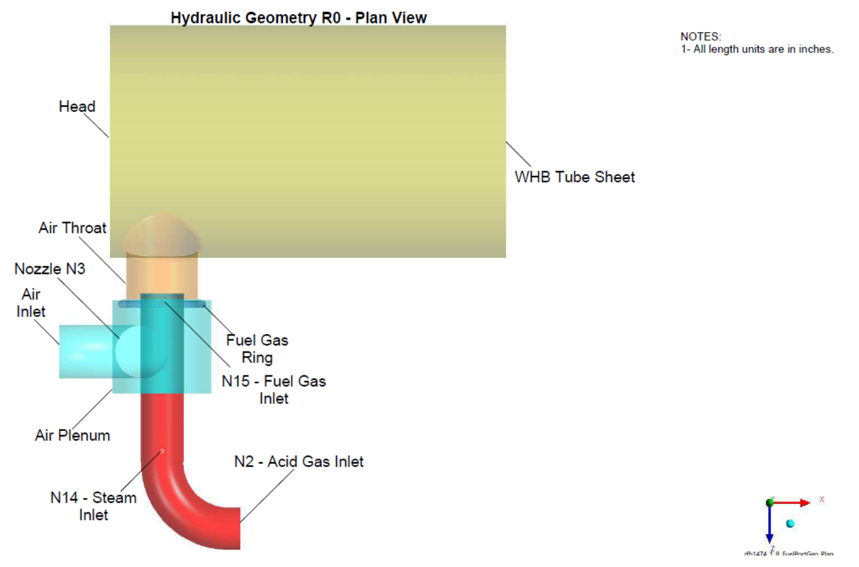
Simulation – Shell Isometric View



Simulation – Shell Top/Side View



Side View

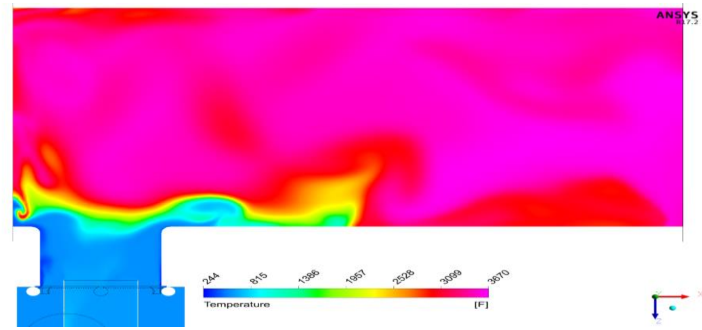


Top View

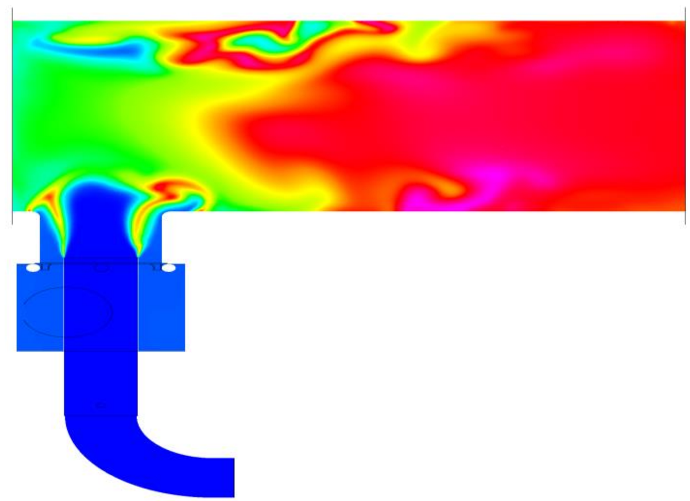
Simulation – CFD Simulation Cases

Two CFD simulation cases

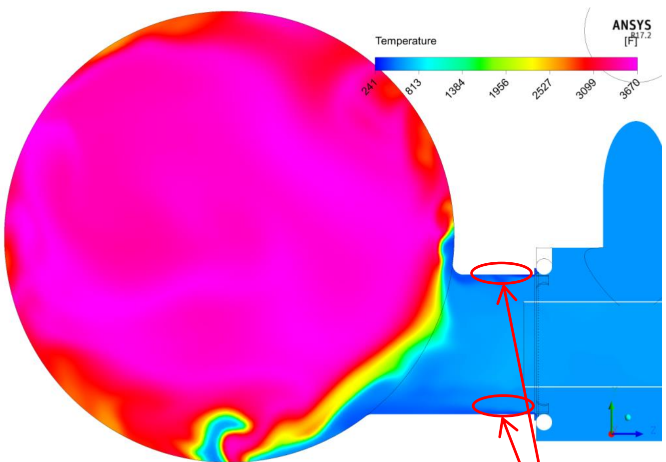
1. Fuel Gas Operation
   - Lack of quenching by steam resulting in high temperature >3500°F



2. Acid Gas Operation
   - Less than optimal mixing (expected with a tangential burner), which results in max refractory temp. of 2002°F. Common and completely benign to sound refractory system.

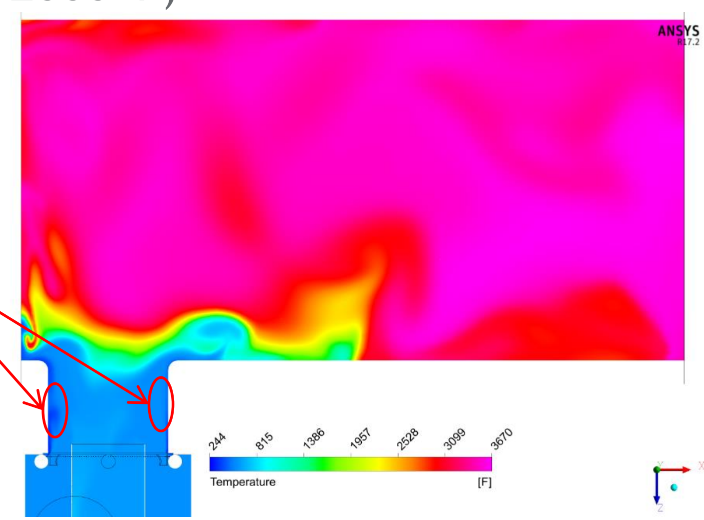


Study – CFD Simulation (Fuel Gas Case)



- Cold ignition firing rate ~50MMBtu/h with adiabatic flame T > 3600˚F
- Significant time delay before addition of tempering medium (T > 2000˚F)

Operating the burner at very low fuel gas firing rates poses a very high risk of flame stabilization within the air throat, and catastrophic failure due to flame anchoring on/contact with the air throat wall.



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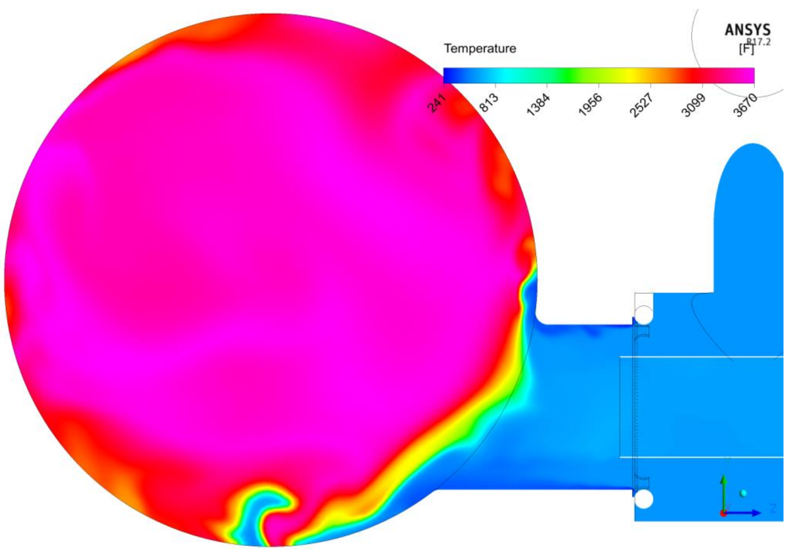
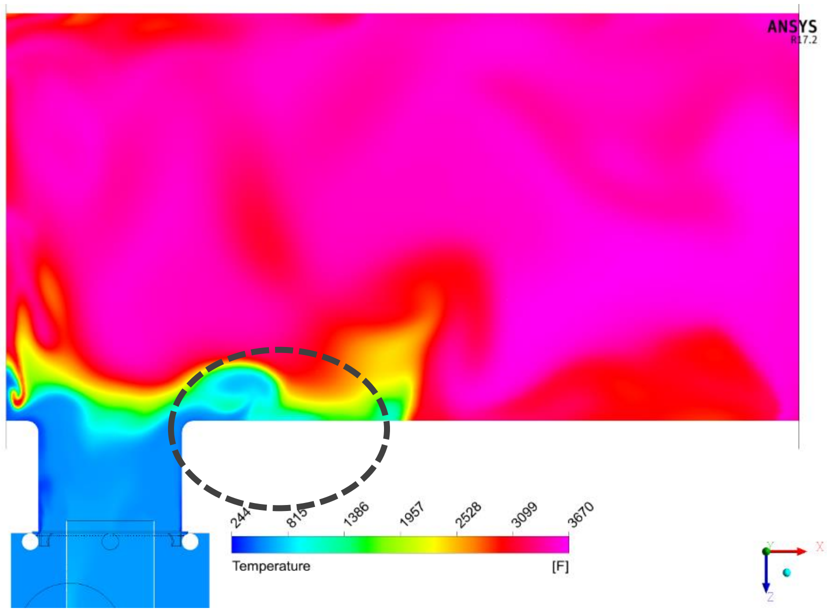


- Lack of quenching by steam resulting in high temperature >3500°F
- No refractory in these units can endure these temperatures for very long
- Tubesheet refractory is especially sensitive to thermal shock



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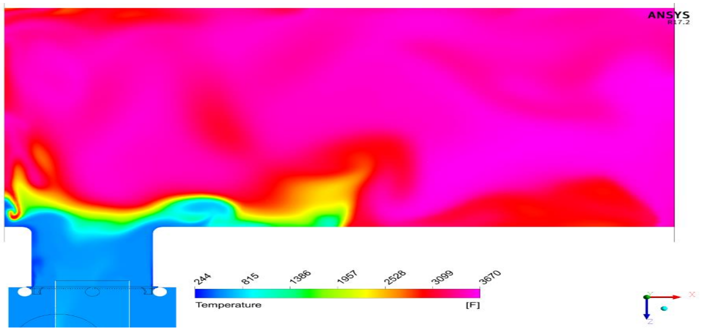

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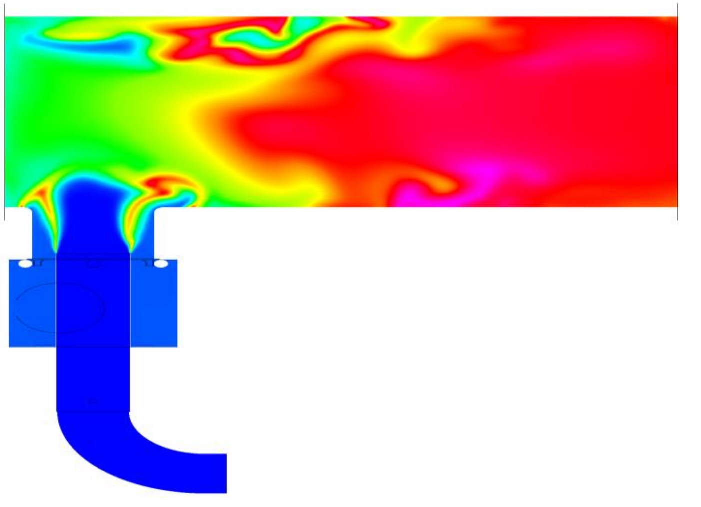
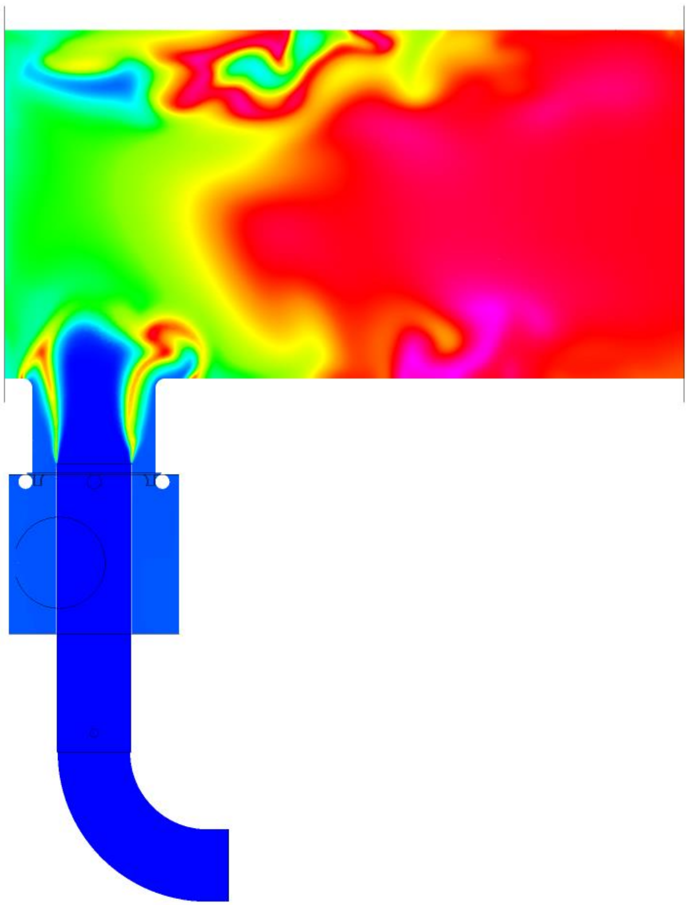
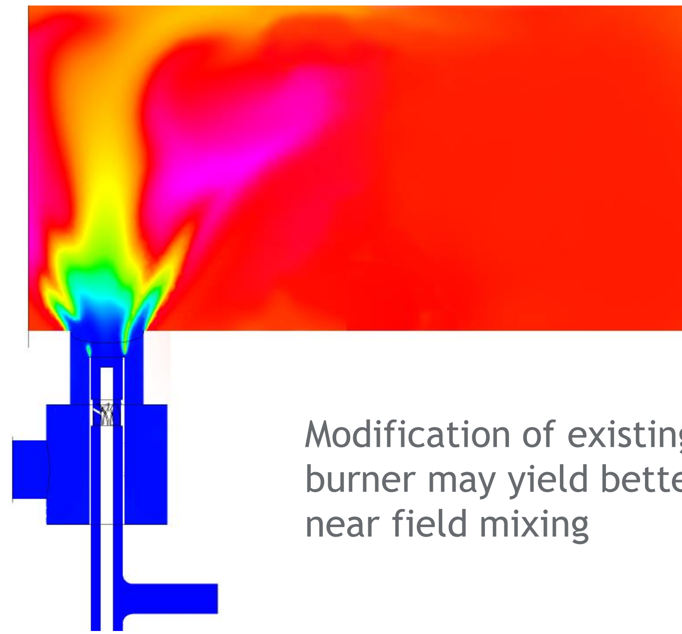


Study – CFD Simulation

Current Burner



Proposed New Burner



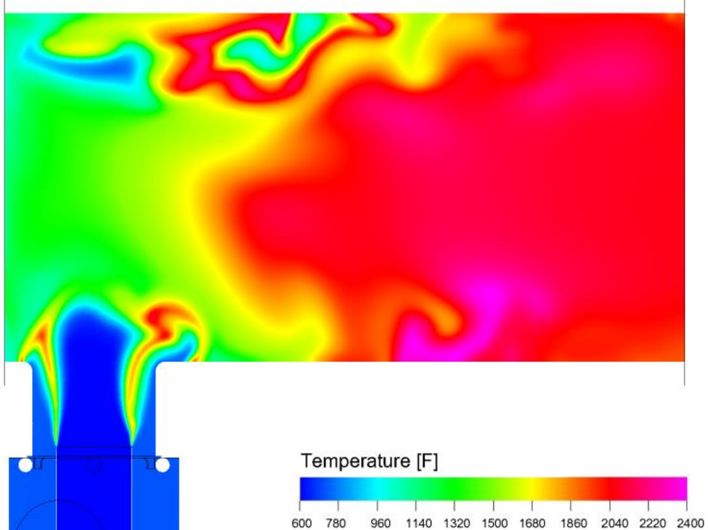
Modification of existing burner may yield better near field mixing

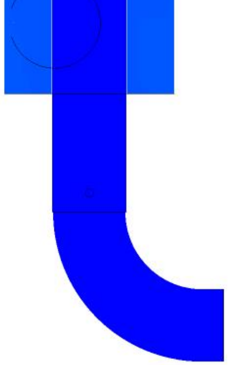
Central fuel gas gun

Acid gas flow conditioner

Study – CFD Simulation

Tangential fired





Very short chamber – slow air/acid gas mixing results in large gas and refractory T variation (~800°F Δ internal)

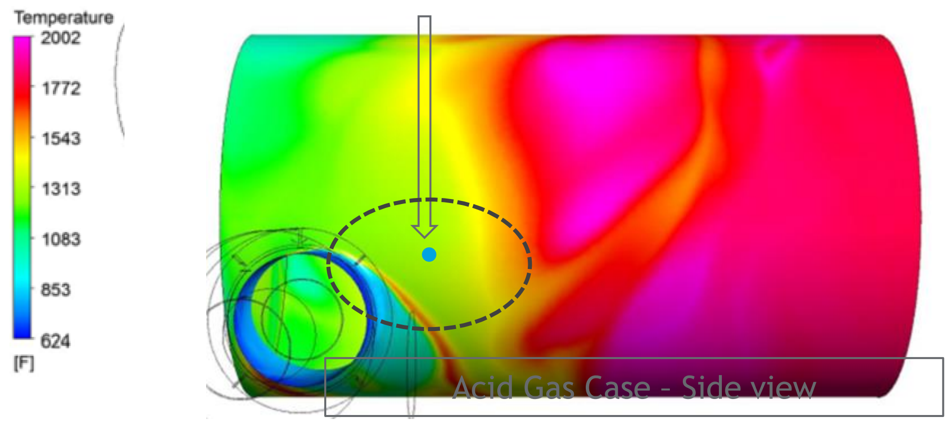
Less than optimal mixing due to tangential burner with max refractory temperature of 2002°F and 800 °F variation

Typical End fired Unit

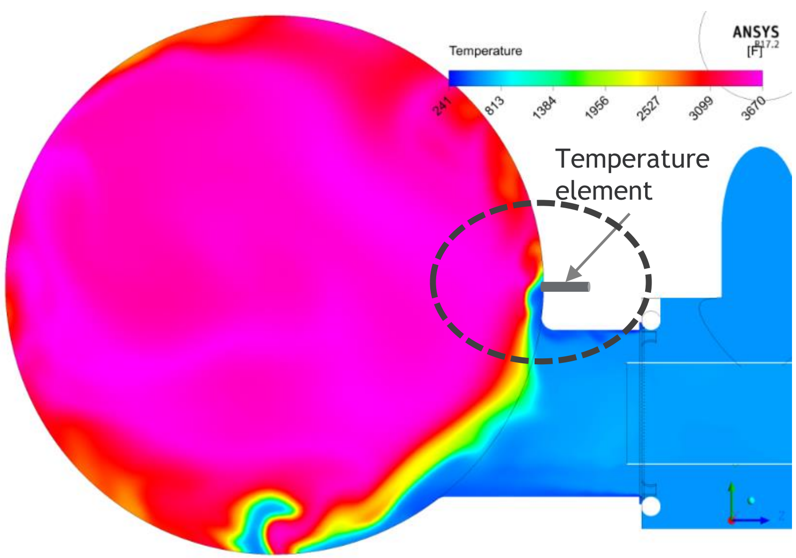
End fired burner would yield much faster mixing

Study – Simulation (Temperature Element)

Temperature Element3 o'clock position



Fuel Gas Case – Cross sectional view



Findings & Recommendations

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Findings –

- **Material (Refractory):**
  - Failures were more common near tubesheet ferrules
  - Discolored refractory found after every T&I
  - High iron content and low creep resistance (refractory & back up) layers
- **Design**
  - Current refractory lining design requires further optimization.
  - Non preferable firing system (Flat wall associated with tangential burner)
  - Refractory around nozzles without back up insulating layer.
  - Improper thermocouples positioning at 3 o'clock position

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Findings –

- **Operation:**
  - Fuel gas contains 15% Propane
  - Excessive temperature during the fuel gas case (No refractory can endure these temperatures for very long)
  - Startup procedure – no tempering steam until >2000°F

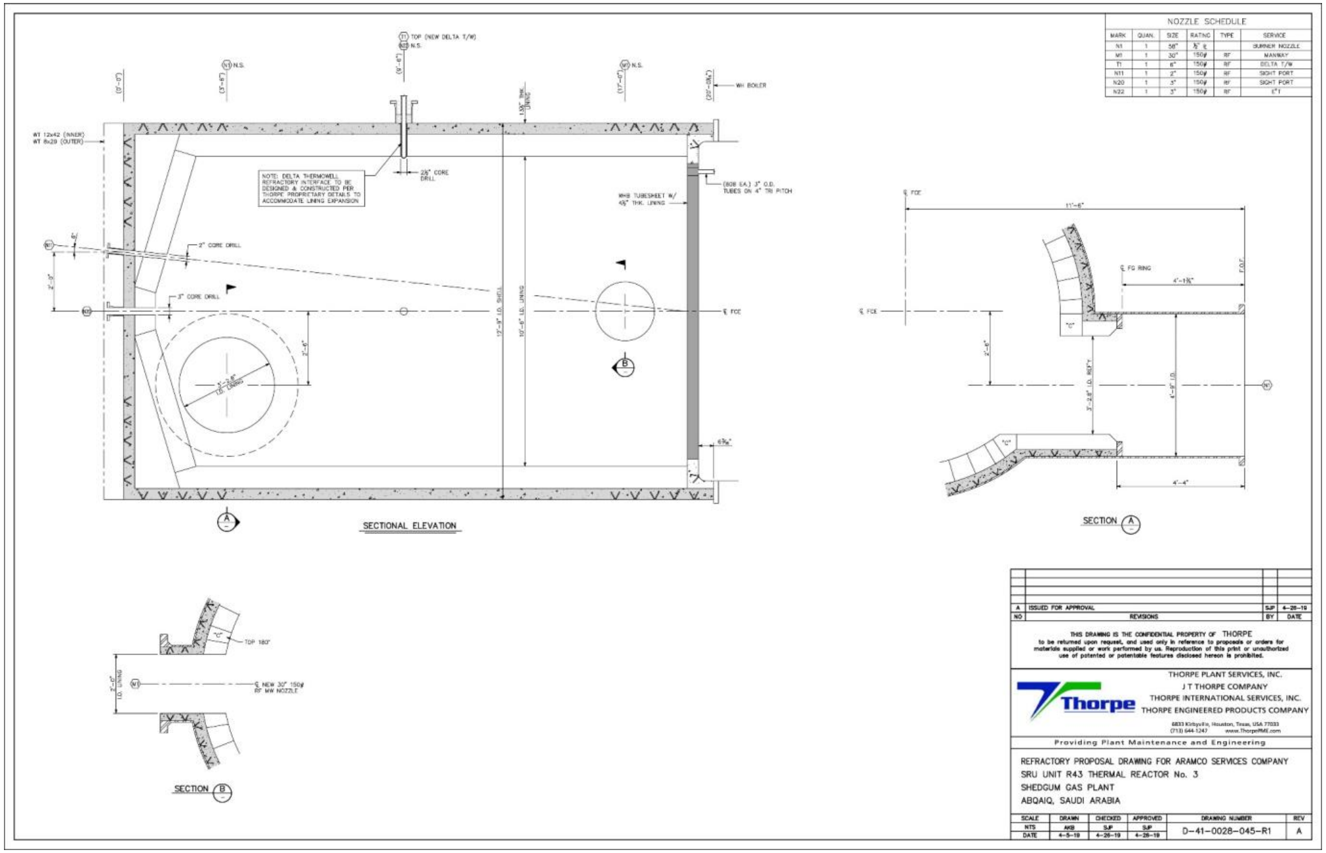
- Ferrules are the most sensitive refractory to thermal shock in thermal reactor.
- From findings it is suspected that thermal shock is the root cause of the failures.

First shutdown post study showing hot face brick failure at the 12 o'clock position

Recommendations –

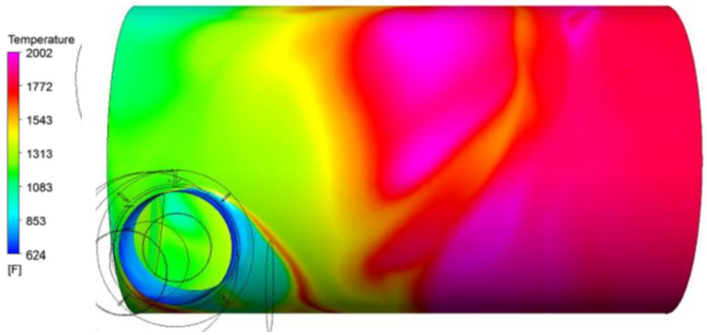
- Upgrade refractory lining system.
  - Utilize self supported brick shallow cone hotface on flat endwall
  - Utilize a higher temperature hotface brick (higher creep resistance and lower iron content)
  - Utilize hotface brick shape with better keying action (remove T&G feature)
  - Provide appropriate expansion relief (axially and radially)
  - Utilize hotface bricks around nozzles
- Change startup/shutdown procedures
  - Reduce cold ignition firing rate drastically
  - Use tempering medium (eg. steam or nitrogen)
  - Use high excess air for controlled warmup for SRU train free of sulphur
- Add two Thermocouple in the 12 o'clock position(s)
- Incorporate burner modifications
  - Use warmup burner sized for 2 to 10MMBtu/h

Refractory Lining Recommendation

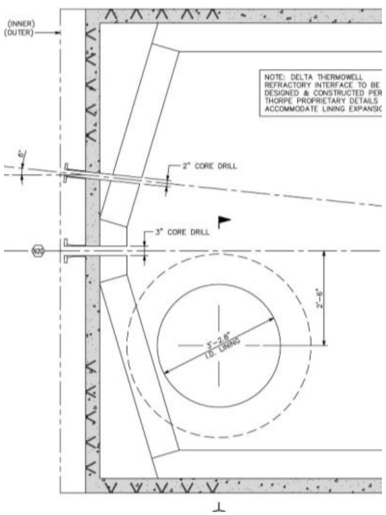


Refractory Lining Recommendation

Acid Gas Case – Refractory Temps

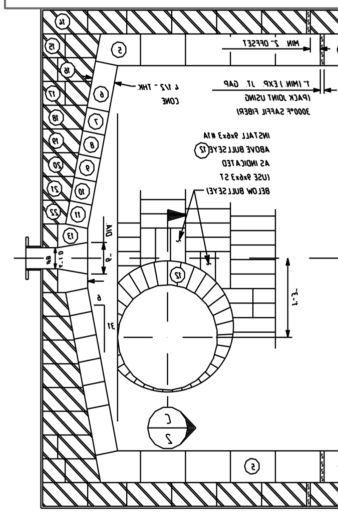


Internal Temperature Variance - ~800˚F



Proposed – Outline Approach

Thorpe – Past Successful Project



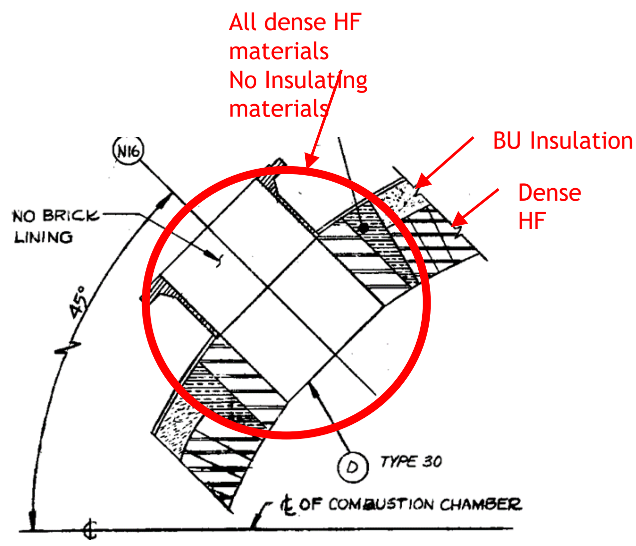
Lining Recommendation

(back up slide)

Improve design at all nozzles utilizing hotface brick construction with proper insulation backup

Original Design

- No insulation backup around or inside nozzle



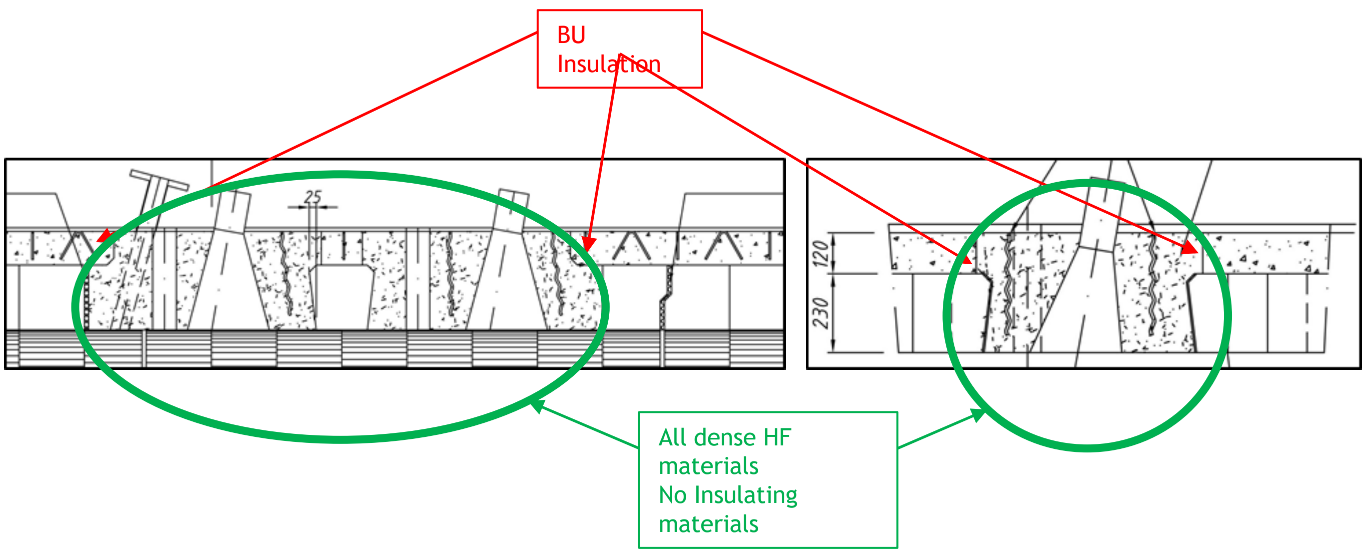
Refractory Lining Recommendation

(back up slide)

Improve design at all nozzles utilizing hotface brick construction with proper insulation backup

Retrofit Design

- No insulation backup at nozzles



Refractory Lining Recommendation

(back up slide)

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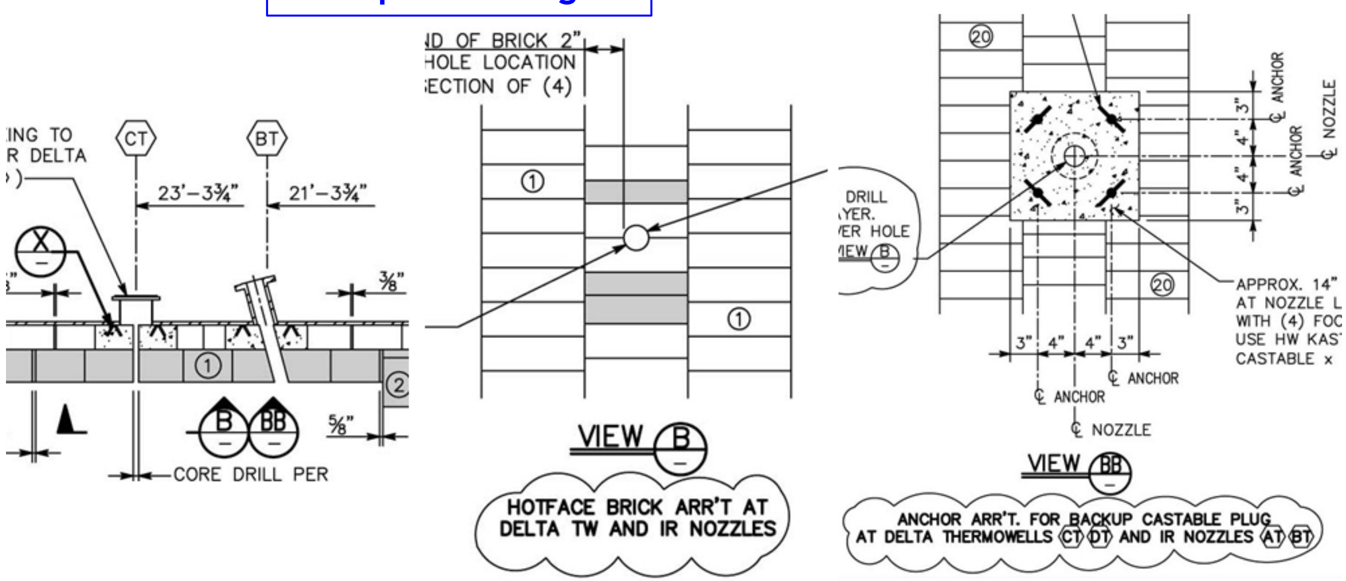
Proposed Design



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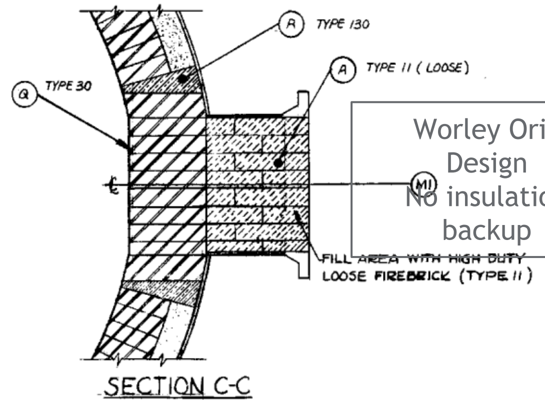
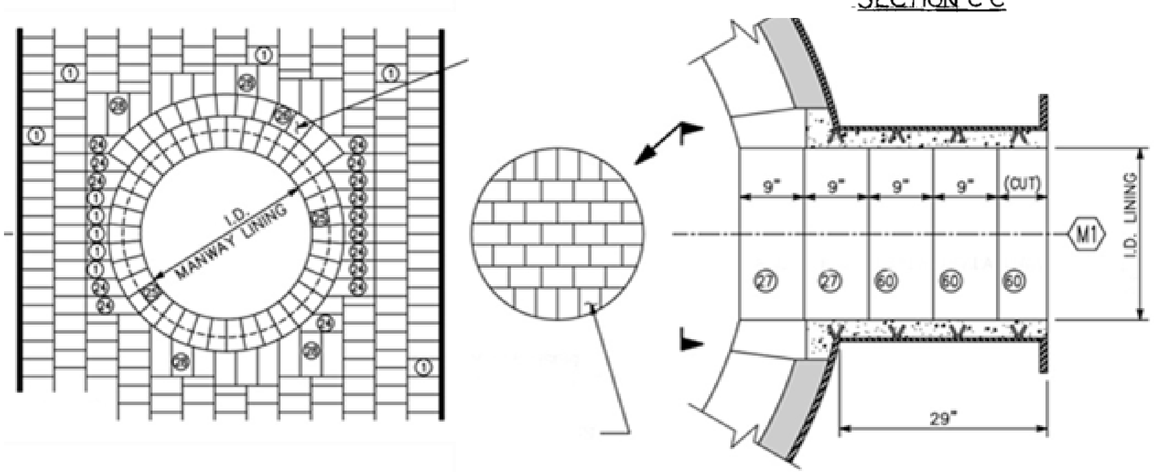
Refractory Lining Recommendation

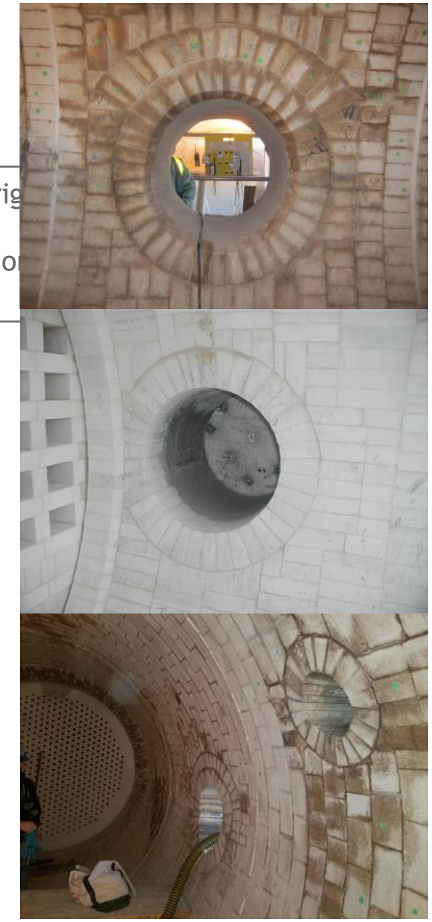
Suggest re-installing manway nozzle w/ proper refractory design



Worley Orig Design
No insulation backup

Proposed Design





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Conclusion

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Conclusion – Benefits/Lessons Learned

- Developed framework for conducting study on SRU.
- Importance of simulation to identify ideal lining design and locations for monitoring critical temperatures.
- Importance of temperature moderation during operation/shutdown/startup to preserve Refractory life.
- Refractory material to be 90% alumina, and iron content not more than 0.2%

- Refractory lining is a “System”,…….composed of multiple individual technology elements. No one design element will “Make” the system work. It is how all of the individual design elements work as a “System”

Conclusion – Path forward

- Study on all existing SRU units in Saudi Aramco.
- Establishing alignment between Licensor, Burner Designer, and Refractory Designer during new project.
- CFD field is being introduced to Aramco Consulting Service Department to improve quality of consultations.
- Updating specs for Refractory material selection.

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