Institute of Refractories Engineers

Thermal Shock and Thermal Stress

How to Avoid Damage to Refractory Linings

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- Material Selection
- Lining Design
- Operation

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Background

Thermal stresses

- Stresses between different components of a lining
- Restrained expansion

Thermal Shock

- Stresses within each component (eg brick)
- Temperature changes
- Phase Changes

Thermal Shock is transient, thermal stresses are always present

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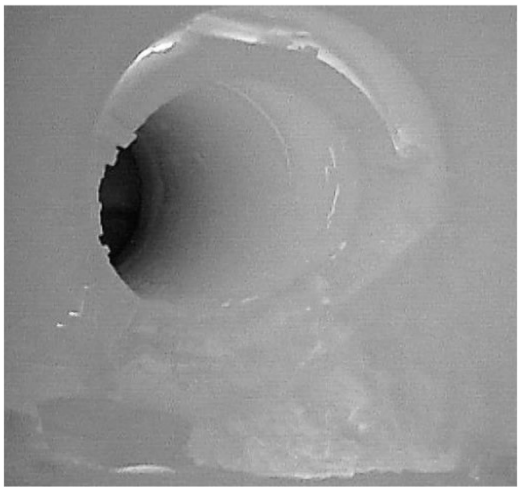
What Damage Can Occur?

Cracks
Spalling
Partial Collapse
Total Collapse



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Material Selection

- Select for Thermal Shock Resistance
  - HIGH Thermal Shock Parameters
  - GOOD Thermal Shock Test Results
- Select for Thermal Stresses
  - LOW Thermal Expansion Coefficient
  - LOW Elastic Modulus
  - HIGH Strength

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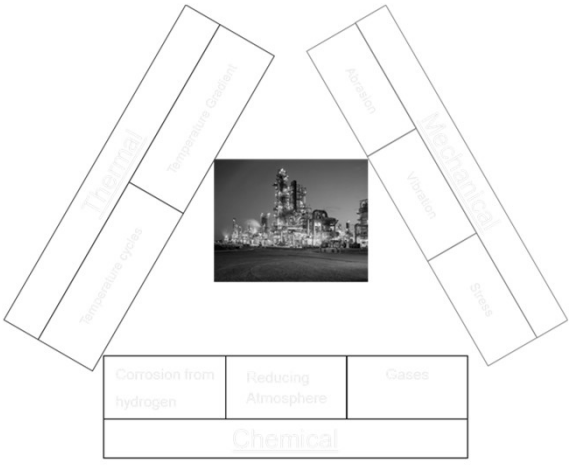
Material Selection

Why NOT Thermal Shock Resistance or Thermal Stress



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Material Selection - Examples

Silica Brick used in Stoves and Coke Ovens
- Worst thermal shock resistance
- Very slow heat up needed

- High Temperature Load Bearing per £

99% Alumina Brick used in petro-chem
- Poor Thermal shock resistance
- High Thermal Stresses

- Resistance to hydrogen gas

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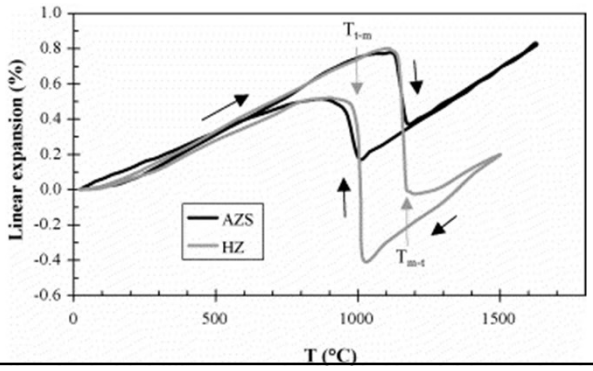
Example – Fused Cast Blocks

$ZrO_2 – Al_2O_3 – SiO_2$ Fused Cast Shapes

Phases present – Mullite and Baddeleyite
- Phase change on heating and cooling



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Application in Chemical Industry

- Fused cast blocks selected for excellent resistance to chemistry of the process.
- Specified Operating Temperature 1000-1100°C – BELOW transition temperature on heating
- Real Operating Temperatures show regular spikes to 1200°C
- Result….

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Lining Design

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Thermal Expansion - Reminder

Thermal Expansion is NOT the same as PLC.
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Thermal Stresses

Restrained Thermal Expansion can and generate VERY high forces… Failure

BUT

Too much expansion allowance can lead to gaps in lining… Loss of containment

Need to consider start up and operating conditions

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Incorrect Expansion Allowance

Too Little Allowance
Stress → Cracking → Spalling

Too Much Allowance
Loose Lining → Movement → Collapse

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Calculating Thermal Stress and Expansion

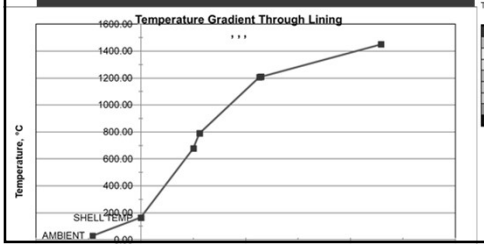
Traditional Calculation

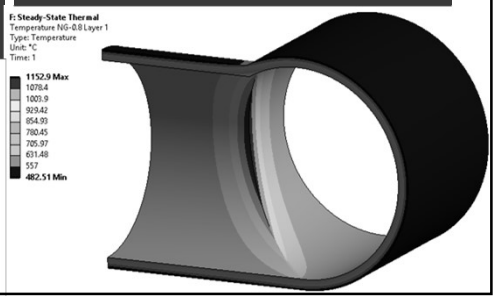
1. 1D model of lining temp profile
2. Simple Expansion Calculation
3. Apply Expansion Allowance based on Experience
4. 1D Calculation of Stress

FE Modelling

2D or 3D model of temp profile, expansion and stress.

More accurate, costly, time consuming





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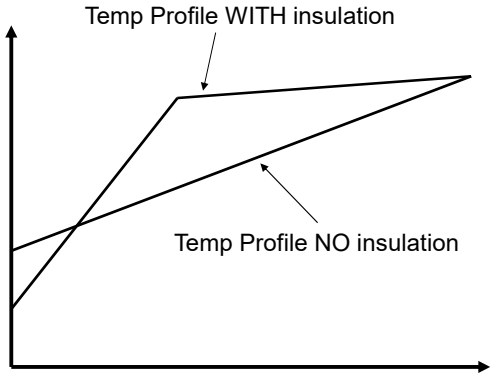
Example – Effect of Insulation



With Insulation
- Higher temp of hot face layer(s)
  - Greater expansion forces
- Lower Shell Temp
  - Less relief of stress
- GREATER FORCES on Shell and Lining

- Crushing of Insulation may protect hot face and shell

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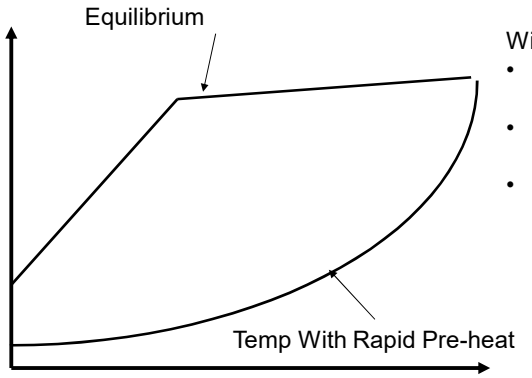
Example – Speed of Pre-heat



With Rapid Pre-heat
- Lower Shell Temp
  - Less relief of stress
- GREATER FORCES on Shell and Lining
- Also thermal shock

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Expansion Allowance

- Different Methods
  - Need appropriate method to materials and application
  - Important to install as designed
  - Presentation on handout

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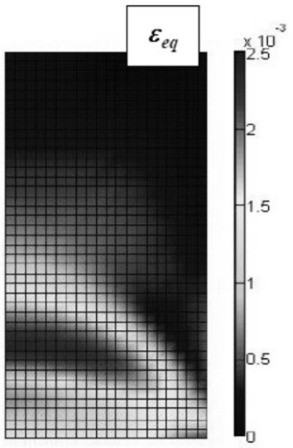
Design for Thermal Shock

- Effect of Piece Size
- For a single piece (brick)
  - Higher stress in larger piece
  - Using smaller bricks makes structure less likely to have thermal shock cracks
  - More joints for stress relief
- BUT
  - Slower construction
  - More joints for loss of containment
  - Less taper on bricks – less stable lining



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Ladle Lining

- Pinch Spalling at vertical joints
- Cracks at middle of course height

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Operational Factors

Operational Factors Affecting Thermal Stresses

- Excess Temperature
  - Higher Temperature than design
  - Lining is hotter than expected
  - More thermal expansion than expected
  - Higher stresses
  - Risk of Damage
- Expansion Joints/gaps not work as required
  - Dust blocking movement
  - Penetration by metal/slag/other

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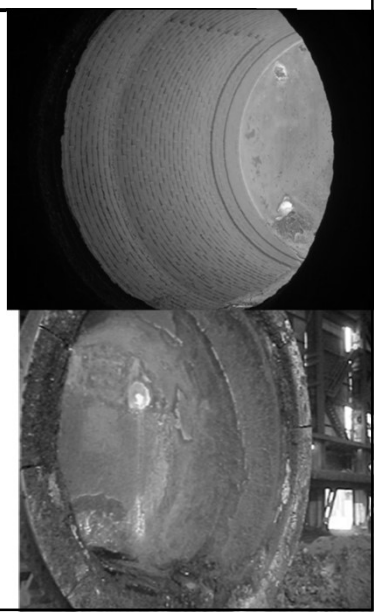
Operational Factors

Operational Factors Affecting Thermal Shock

- Delays
  - Lining cools during delay
  - When operation resumes, rapid heat-up of the lining can occur
  - → Thermal Shock
  - Heating of lining during waiting times
  - Keeping heat in lining
    - Ladle Lids
    - Close exhaust duct
    - etc



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Maintenance Factors

Maintenance Omissions

- Failure to adjust buckstays
- Expansion Bellows Damage
- Incorrect Shell Cooling
- etc etc

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Comissioning

- Incorrect Heat Up → Thermal Shock Damage
- Why Heat Up too fast
  - Commercial Pressures – plant availability
  - Operational Pressures – Poor control of heat up process
  - Oxidation of lining during pre-heat

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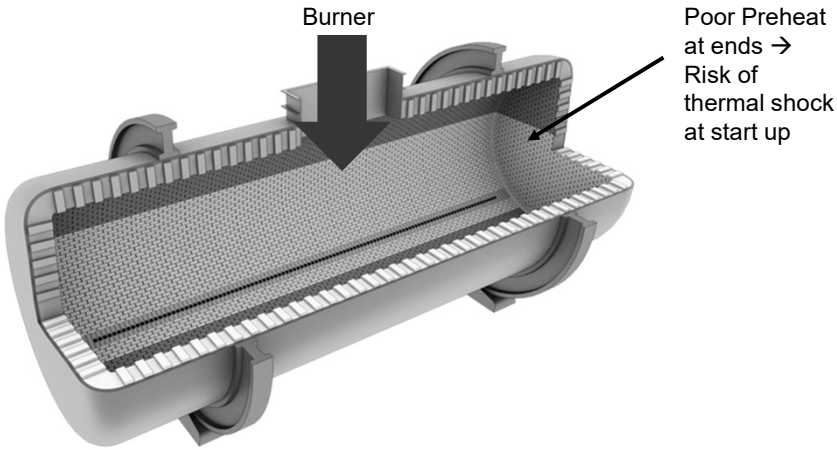
Pre-heat Design



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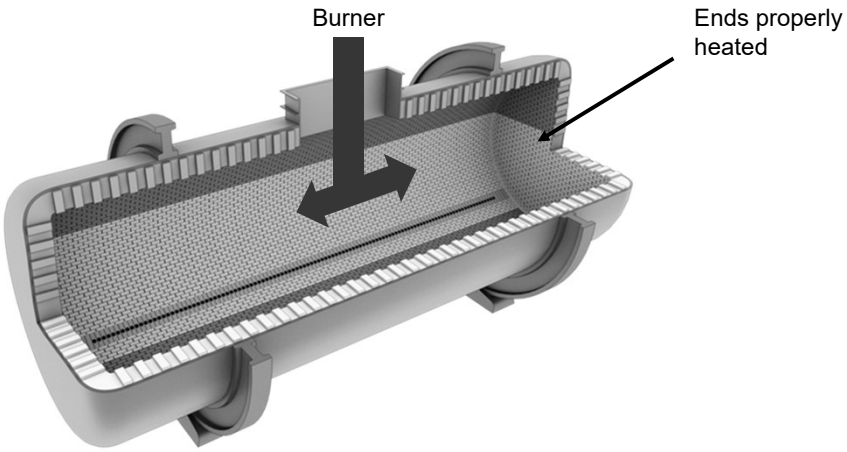
Pre-heat Design



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Thank You

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