Institute of Refractories Engineers

Keeping the Heat In

Sheffield
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Sam Franklin

INTRODUCTION

Course Aim

To provide an understanding of heat flow through refractory linings and the different types of insulating refractories available.

The advantages and disadvantages of different types of insulation materials will be presented

Contents

Heat and Heat Flow
- How to Insulate
- Thermal Conductivity
- Thermal Calculations

Types of Insulating Materials
- Monolithics
- Bricks
- Fibre Products
- Special Products

Application and Material Selection

Context

Refractories are used to contain high temperature processes
- Temperatures up to 1800°C are common

We need to insulate linings to
- Keep the heat where it is wanted
- Protect surrounding equipment
- Protect people
- Save energy and money

Heat and Temperature

Heat is a form of energy.
Temperature is a measure of the heat (energy) content of a material

If a material cools down it is losing heat energy

If a material heats up…..

A material can get hotter if
- We use energy (eg burning a fuel)
- Heat flows into the material from somewhere else

A material can get colder if it looses heat (energy) to something else

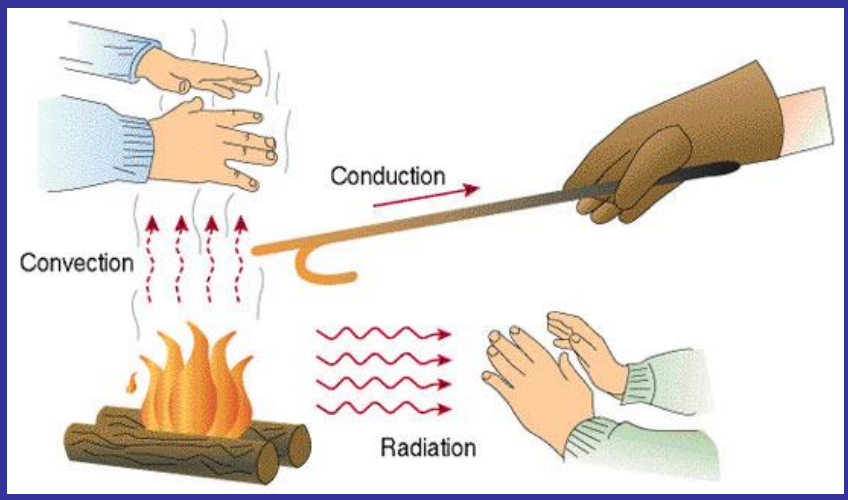
Heat Flow

Heat can only flow in one direction

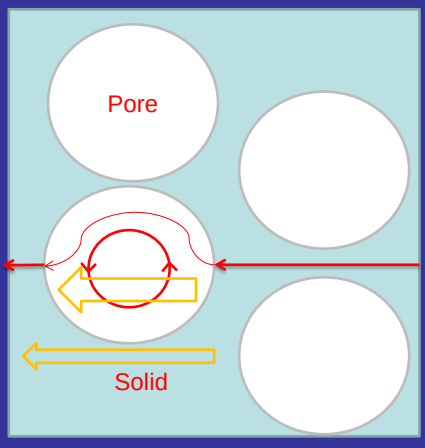
From Hot to Cold

So Hot things tend to cool down
and warm things tend to heat up.

How Does Heat Flow



Heat Transfer at Within a Refractory



Conduction Through Solid Ref'y

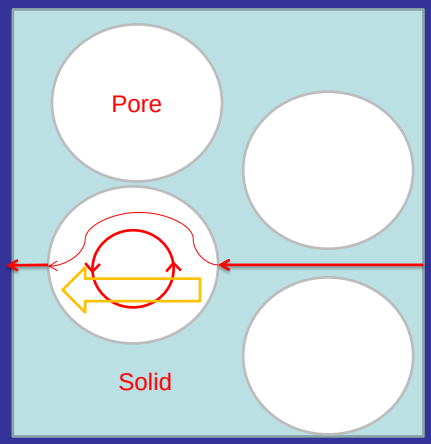
Conduction in Gas

Convection of gas in pore

Radiation across pore

Radiation in Solid

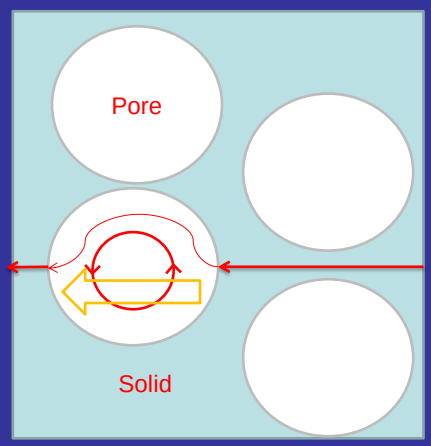
Reducing Heat Transfer at Within a Refractory



Conduction Through Solid Ref'y

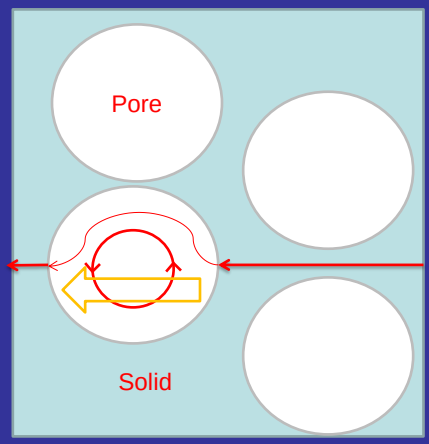
- Less solid material
  - Higher porosity
- Less conducting material
  - Not use Carbon, SiC
  - Alumino-silicate not basic oxide

Heat Transfer at Within a Refractory



Conduction in Gas

Heat Transfer at Within a Refractory

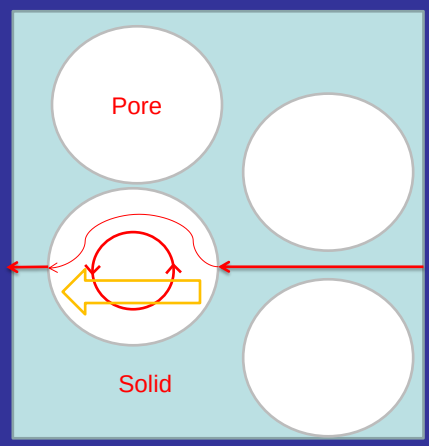


Convection of gas in pore

- Reduce temp difference across pore
- Increase viscous drag

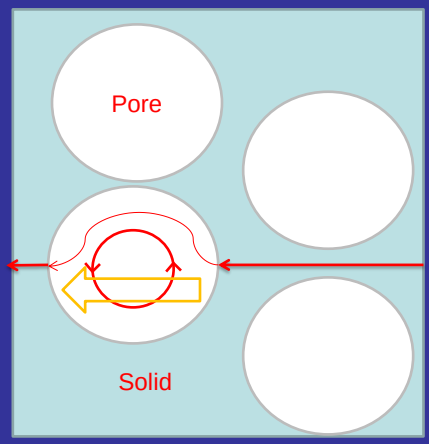
- Smaller pores

Heat Transfer at Within a Refractory



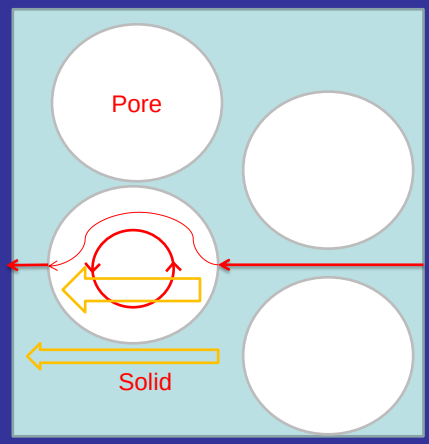
Radiation across pore

Heat Transfer at Within a Refractory



Radiation across pore
- Low surface emissivity
- Many surfaces through thickness
  - Smaller pores
  - Oriented pores

Heat Transfer at Within a Refractory



Radiation Through Solid
- Opaque material
- Grain boundaries

Thermal Conductivity

Thermal Conductivity is a measure of how much heat flows through a material.
To calculate actual heat flow and energy loss, need to know thickness and area
Thermal conductivity is measured in W/mK

Thermal Conductivity – Typical Values

	W/mK
Copper	390
Aluminium	200
Wood	0.04
Air	0.025 (excludes convection)
Alumina Refractories	1 - 3
Basic Refractories	2.5 - 6
Carbon Containing Refractories	5 - 25
Insulating Refractories	0.03 - 0.6

Thermal Conductivity

Thermal Conductivity

- Varies with temperature
  - Room Temperature Conductivity may be 30% of that at service temperature
- May Vary with Direction
  - eg fibre modules
- Different test methods give different results

Thermal Conductivity

Definition by equation

$$Q = k \Delta T . \frac{A}{t}$$

Where

- Q = Heat flow (measured in W or kW)
- k = Thermal Conductivity (measured in W/mK)
- ΔT = Temperature difference
- A = Area
- t = thickness

Thermal Resistance, R

Useful for calculations with more than one layer in a lining….

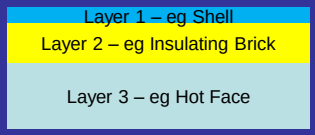
$$R = \frac{t}{k} \quad \text{and} \quad \frac{Q}{A} = \frac{\Delta T}{R}$$

where t = thickness (in m) and k = thermal conductivity (in W/mK)

For several layers

$$R_{all} = R_1 + R_2 + R_3 \ldots\ldots \quad \text{or} \quad R_{all} = \frac{t_1}{k_1} + \frac{t_2}{k_2} + \frac{t_3}{k_3} \ldots\ldots$$

and $\frac{Q}{A} = \frac{\Delta T}{R_{all}}$

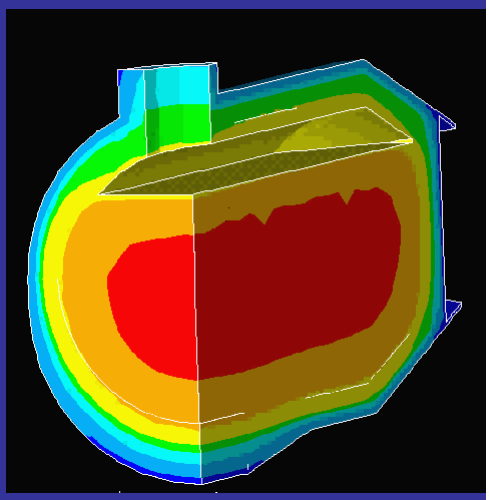


Thermal Calculations

For refractory design, heat flow calculations are needed to ensure

- Maximum temperatures are not exceeded – eg
  - Shell temperature
  - Service temperature for each layer of the lining
- Minimum temperatures are met
  - Acid dew point
- Heat flow is at an acceptable level for production needs
  - Low flow to conserve energy
  - High flow where rapid cooling is needed

Calculations can be a simple spreadsheet or complex mathematical models



Thermal Calculations

The accuracy of a thermal calculation depends on
- How good the thermal model is
- How accurate the thermal conductivity data is
- If it includes all the factors, eg wind

Some safety margin should always be built into a thermal design to allow for errors in a model

Heat flow can change over time
- Degrading of materials
- change to surface of a vessel, eg
  - dust build up,
  - corrosion
  - paint peeling

This can change the heat flow and temperature gradient

Any Questions

Exercise 1 – Insulation Comparison

ANSWERS

Exercise 1 – Insulation Comparison

Part 1

$Q = k \Delta T \cdot \frac{A}{t}$ or rearranging $t = \frac{k \Delta T}{Q/A}$

Q/A is heat flow per square meter = heat flux = 2000W/m^2

$\Delta T = 1000°C$

T = k x 1000/2000

Exercise 1 – Insulation Comparison

Material	Thermal Conductivity k, W/mK	Thickness, mm
Alumina Castable	1.5	750
Insulating Castable	0.5	250
Insulating Firebrick	0.25	125
Ceramic Fibre Board	0.1	50
Microporous panel	0.03	15

Exercise 1 – Insulation Comparison

Part 2

Use $R = \frac{t}{k}$ and $\frac{Q}{A} = \frac{\Delta T}{R}$

Example – 50mm insulation : 200mm hot face

$R = \frac{0.05}{0.1} + \frac{0.20}{1.5} = 0.5 + 0.133 = 0.633$

$Q/A = 1000 / 0.633 = 1579\ W/m^2$

Temp drop across insulation = $Q/A \,.\, R_{ins} = 1579 * 0.5 = 789°C$

Add cold face temp to get interface temp = 889°C

Exercise 1 – Insulation Comparison

Alumina Castable	200	150	100	50
Ceramic Fibre Board	50	100	150	200
R (total)	0.633	1.1	1.567	2.033
Q/A	1579	909	638	492
Interface Temp	989	1009	1057	1084

Types of Insulation

Insulation Monolithics – Ian Spicer
Insulating Firebrick – Dave Woodhead
Fibre Products – Allan Davies
Other Products – Sam Franklin