Institute of Refractories Engineers

Online Training Event 2020

Thermal Gradient Calculations

Contents

Why Calculate Thermal Gradient

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Allows predictions of lining temperature and heat loss from process

Allows thermal expansion to be calculated

Allows material selection to be optimised

What is Steady State

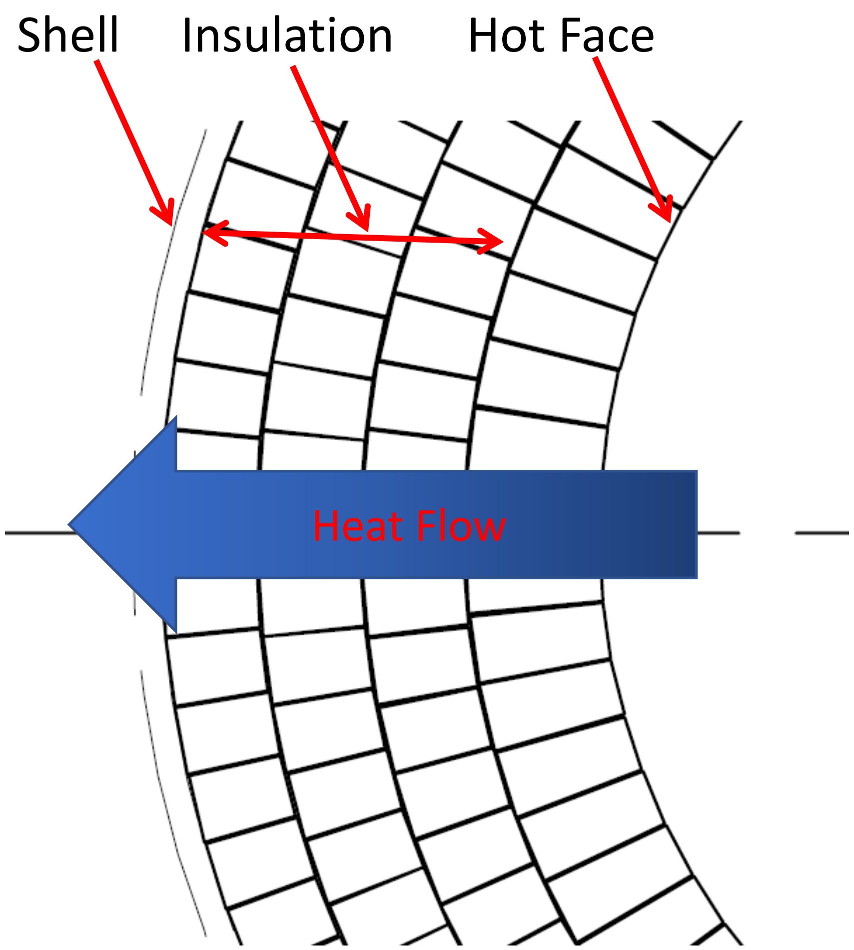
- Means
- Constant hot face temperature
- Constant ambient conditions (temperature, wind etc)
- Energy flowing into hot face of lining is same as energy lost from hot face
- Temperature gradient is not changing with time

- Temperature at any point in lining is highest possible for a given hot face temp

- Takes hours or days to be reached depending on lining

- Simple to model and useful for design

Typical Lining



Heat energy flows from inside to hot face

Heat Flows through lining

Heat energy passes through lining and shell

Temperature gradient through lining

Area of successive layers is different

Temperature Gradient

Automated models

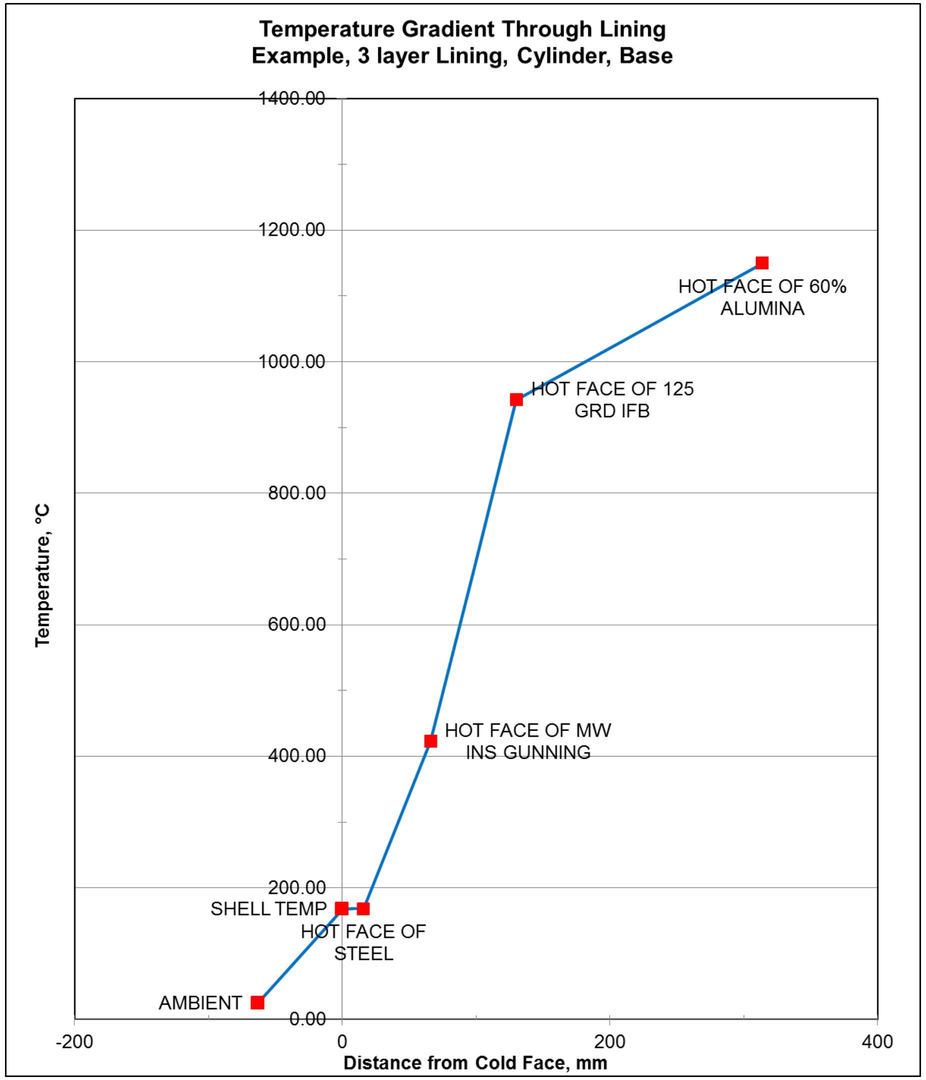
Quick Calculation

Simple to use

Reliability of result

Data used

Is steady state reliable?



How models work - Hot Face

Hot face temperature

Assume steady process temperature

Melt temperature

Gas temperature

Flame temperature

Average from temp measurements

Either

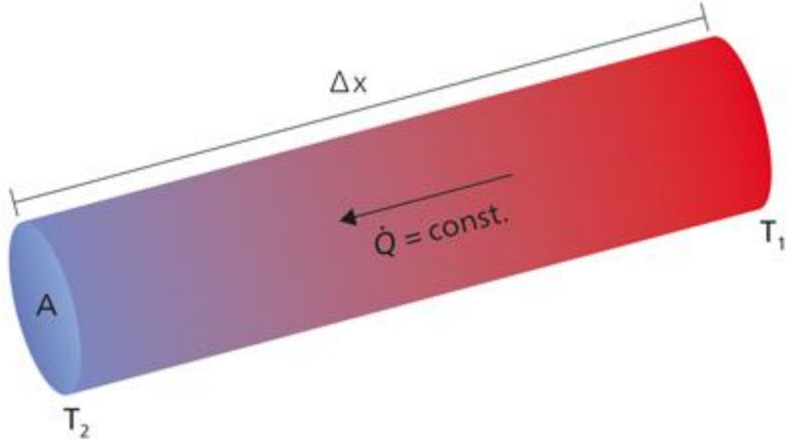
Assume hot face of refractory is at process temp

Or

Apply a heat transfer coefficient between hot face and process

How models work - Flow through Lining

- Thermal Conductivity
- $$W = k\ A\ \Delta T/\Delta x$$
- where
- W = Heat flow
- k = Thermal conductivity
- A = Area
- $\Delta T/\Delta x$ = Temperature Gradient



How models work - Flow through Lining

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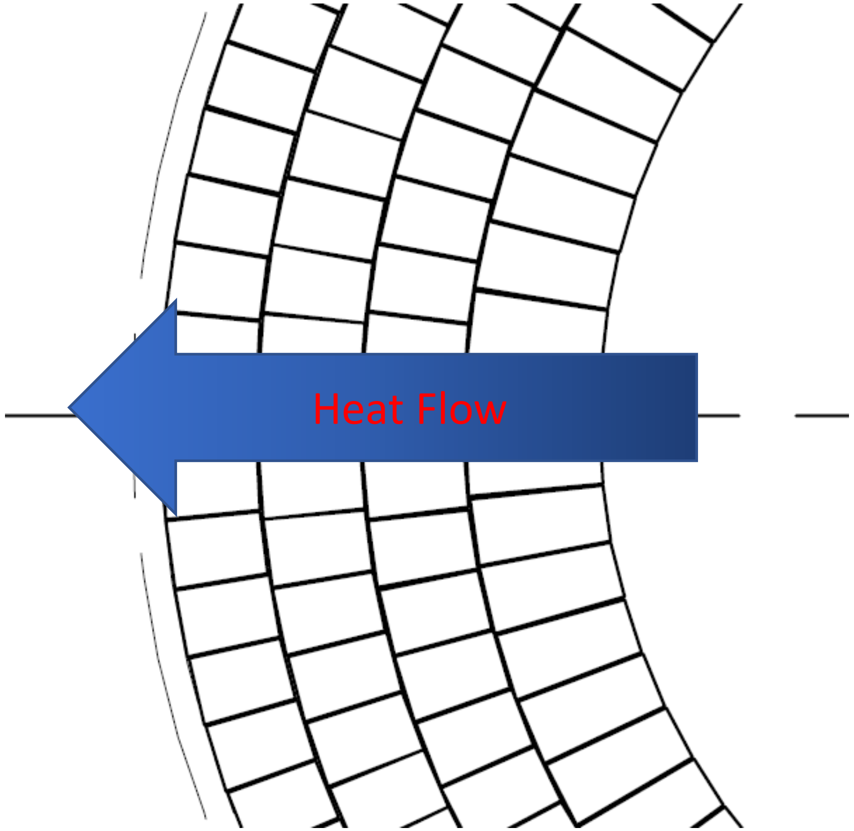
Most linings made up of several layers, each layer has

- different thickness -Δx
- different temp difference ΔT
- different conductivity, k
- different area, A



In steady state, W for each layer is the same

How models work - Flow through Lining

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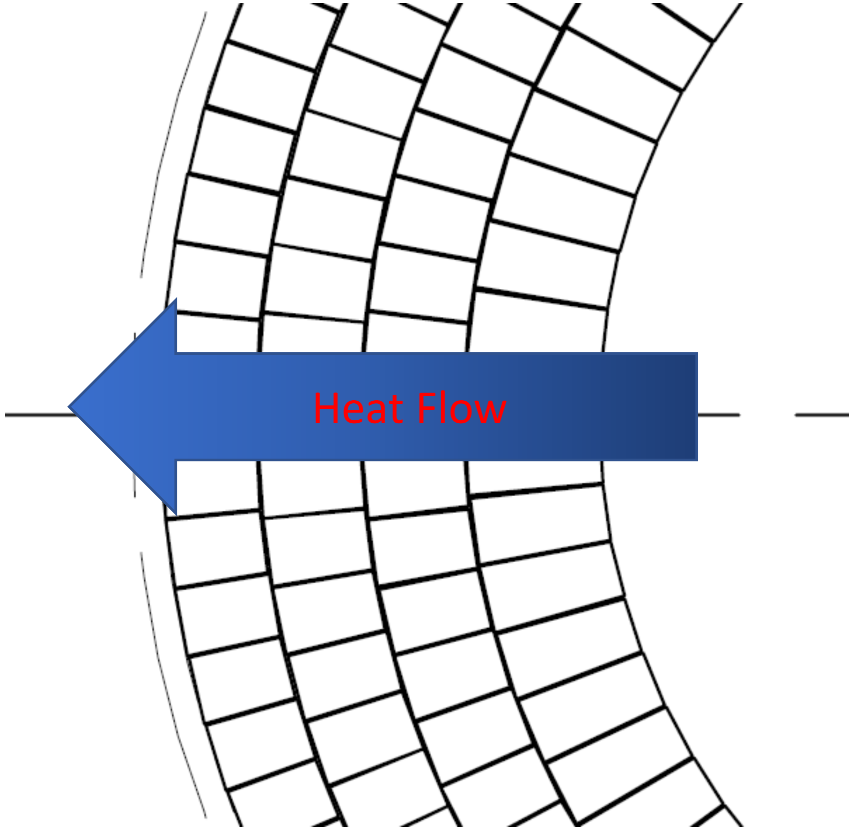
- $W_1 = W_2 = W_{3.....}$

- So

- $k_1 A_1 \Delta T_1/\Delta x_1 = k_2 A_2 \Delta T_2/\Delta x_2$

- Some re-arranging allows a solution to the is known



How models work - Flow through Lining

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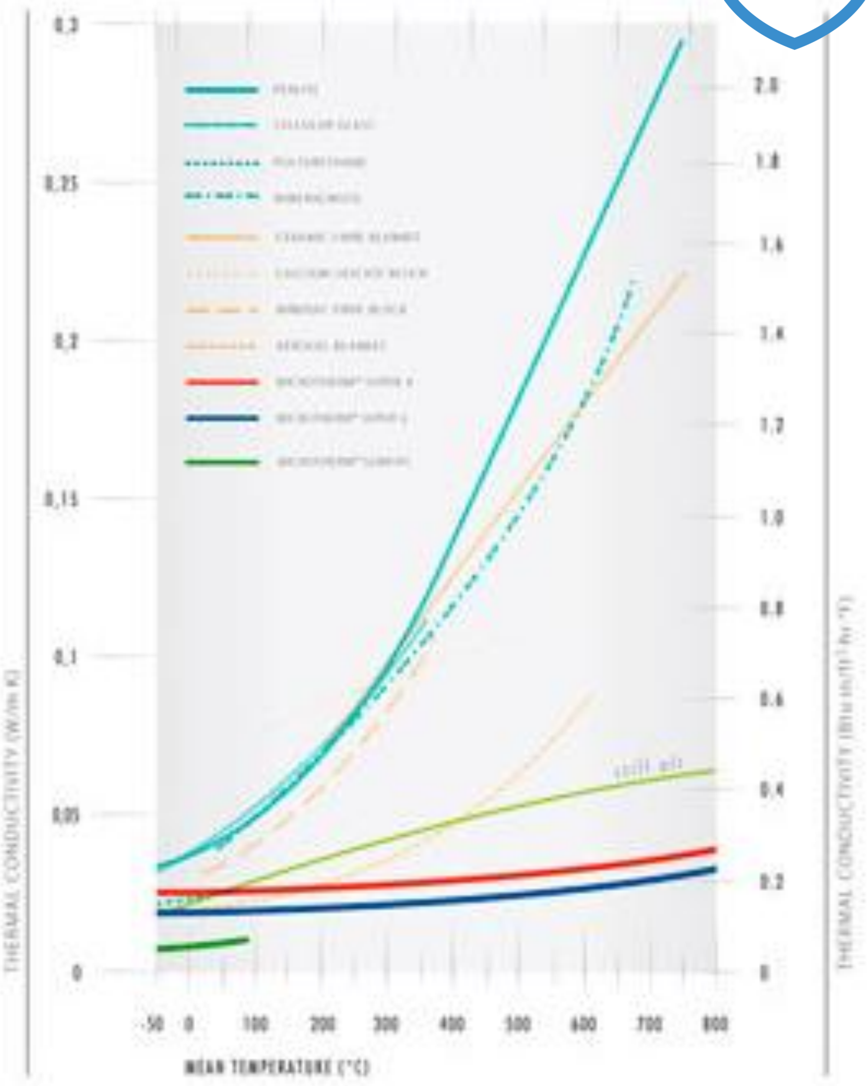
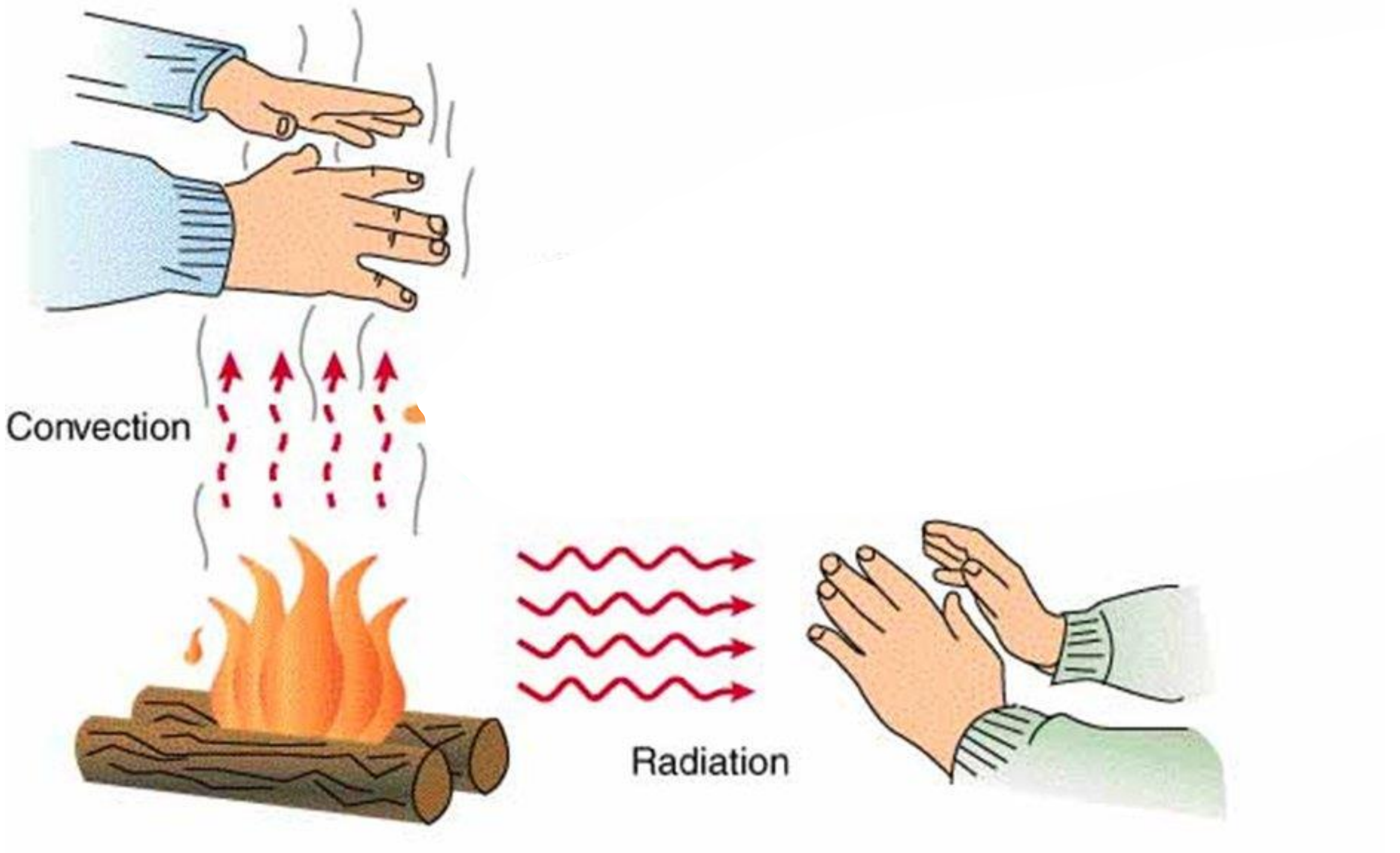
- Thermal Conductivity and temperature
- Thermal conductivity of a material is NOT a constant
- Use value for conductivity at mean temperature of layer
- How do we know mean temperature of layer if we don't know conductivity?



How Models work - Cold face Heat flow

- Heat lost from surface by
- Radiation
- Convection
- Natural
- Forced
- (Conduction)



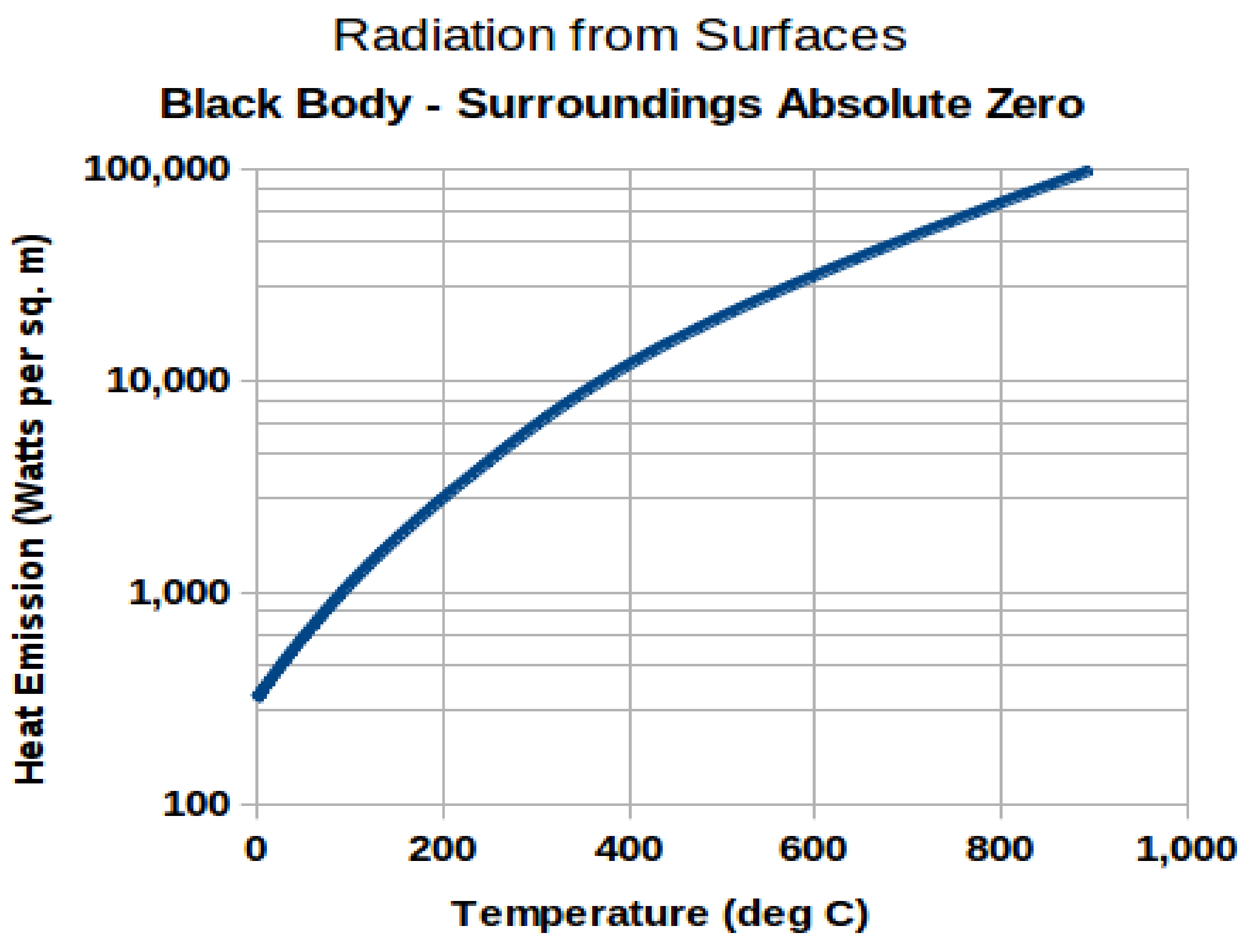
Radiation

- Heat flow depends on
- Shell Temperature
- Ambient Temperature
- Emissivity, e

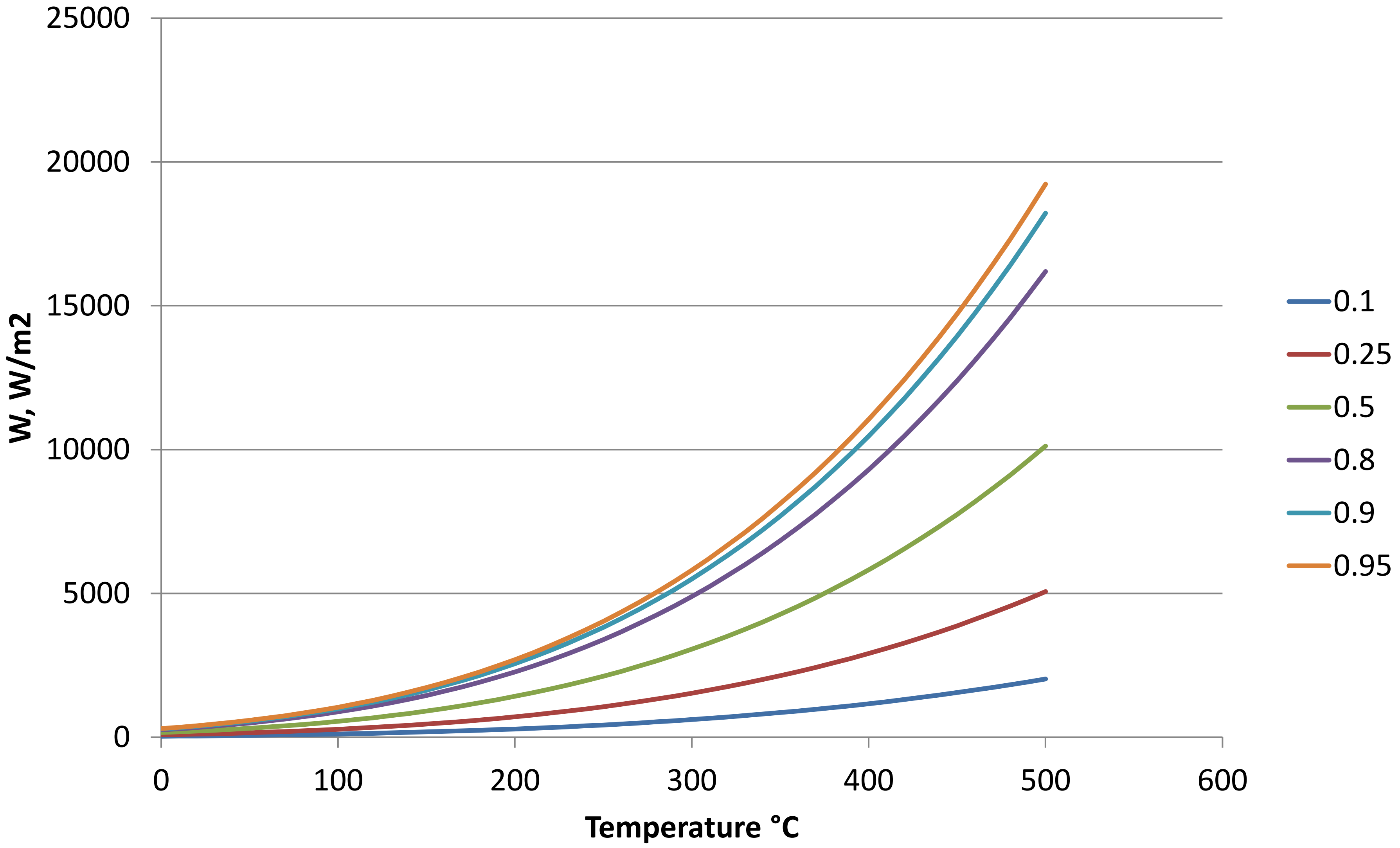
- Steffan Boltzman Law

- $W = e \sigma A T^4$

- where σ is a constant



Radiation



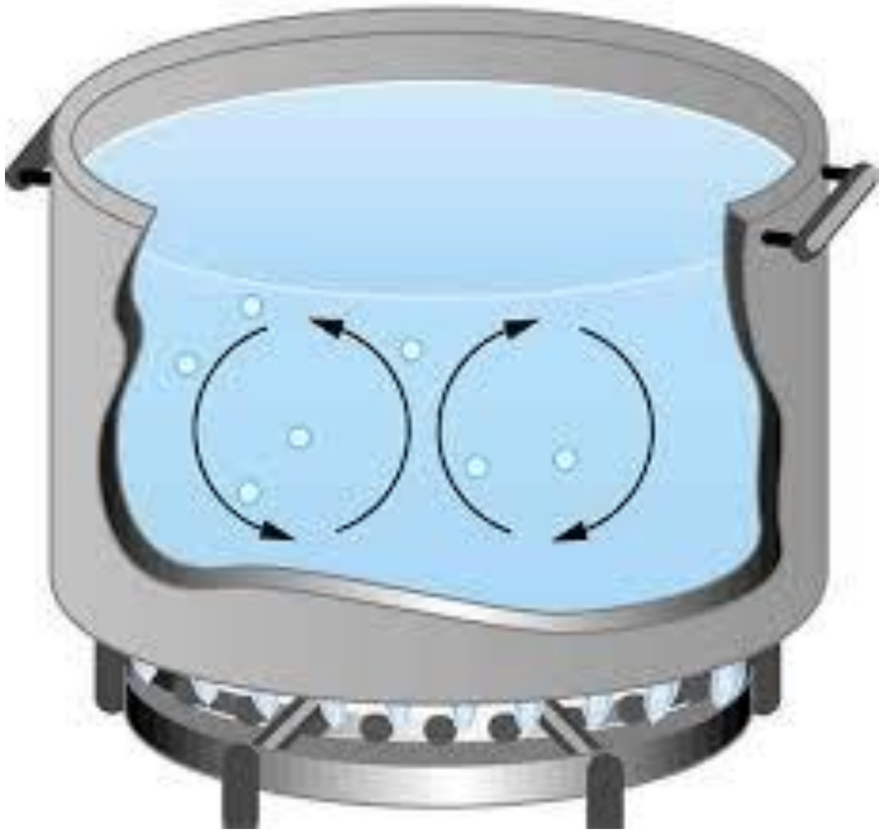
25000
20000
15000
10000
5000
0
W, W/m2
0
100
200
300
400
500
600
Temperature °C
0.1
0.25
0.5
0.8
0.9
0.95

Convection

MUCH more complicated

- Forced convection
  - Air blowers.
  - Water cooling
- Natural Convection
  - Geometry
    - Plate, Cylinder, Sphere etc
  - Angle
    - Vertical, Underside, Topside

Just read a text book on heat transfer…….



Heat Transfer Coefficient

$W = h_c A \Delta T$

where

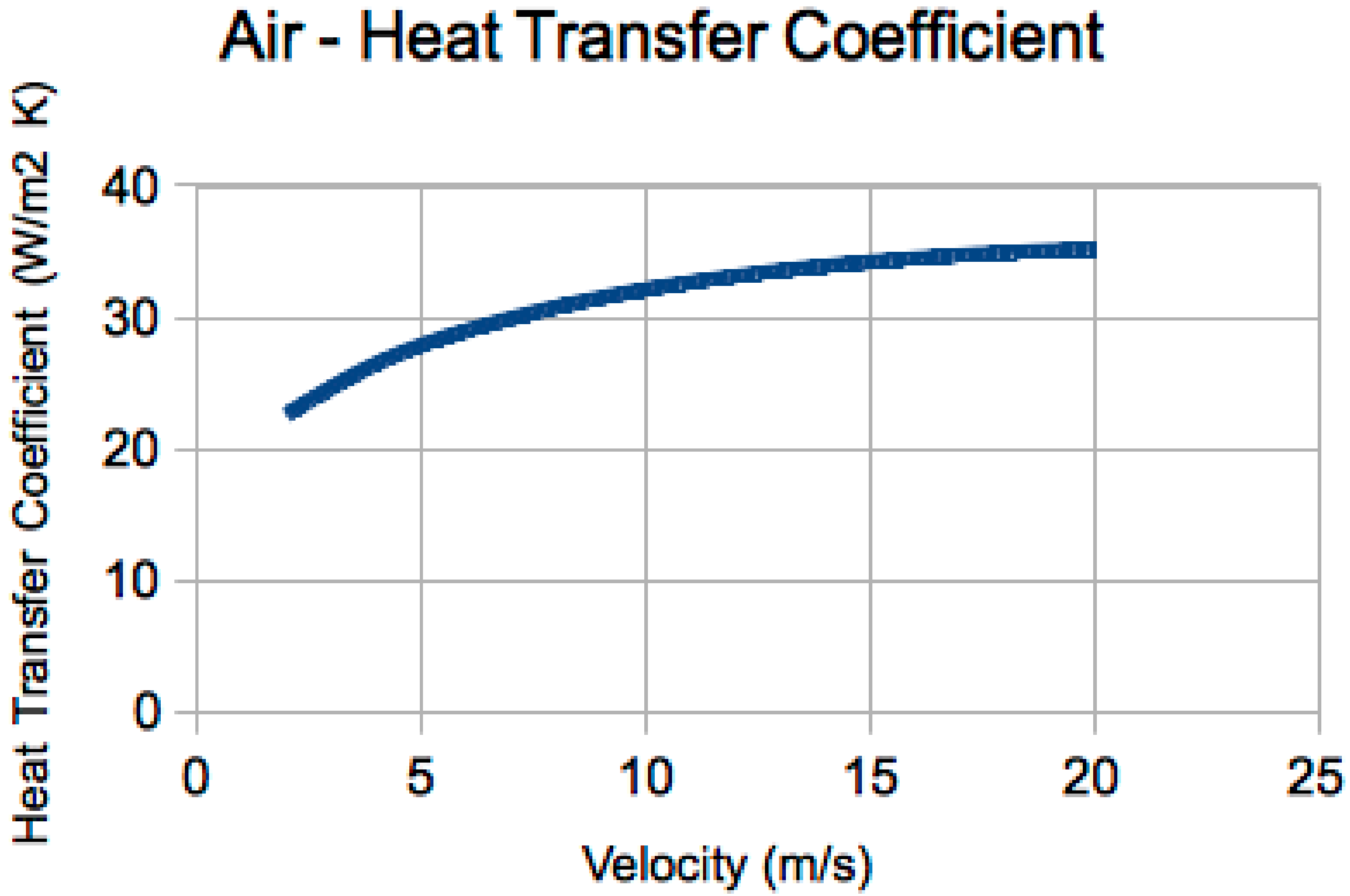
W = heat transferred per unit time (W)
A = heat transfer area of the surface (m^2)
h_c= convective heat transfer (W/(m^2K)
ΔT = temperature difference between the surface and the bulk fluid

For still air over a horizontal cylinder…

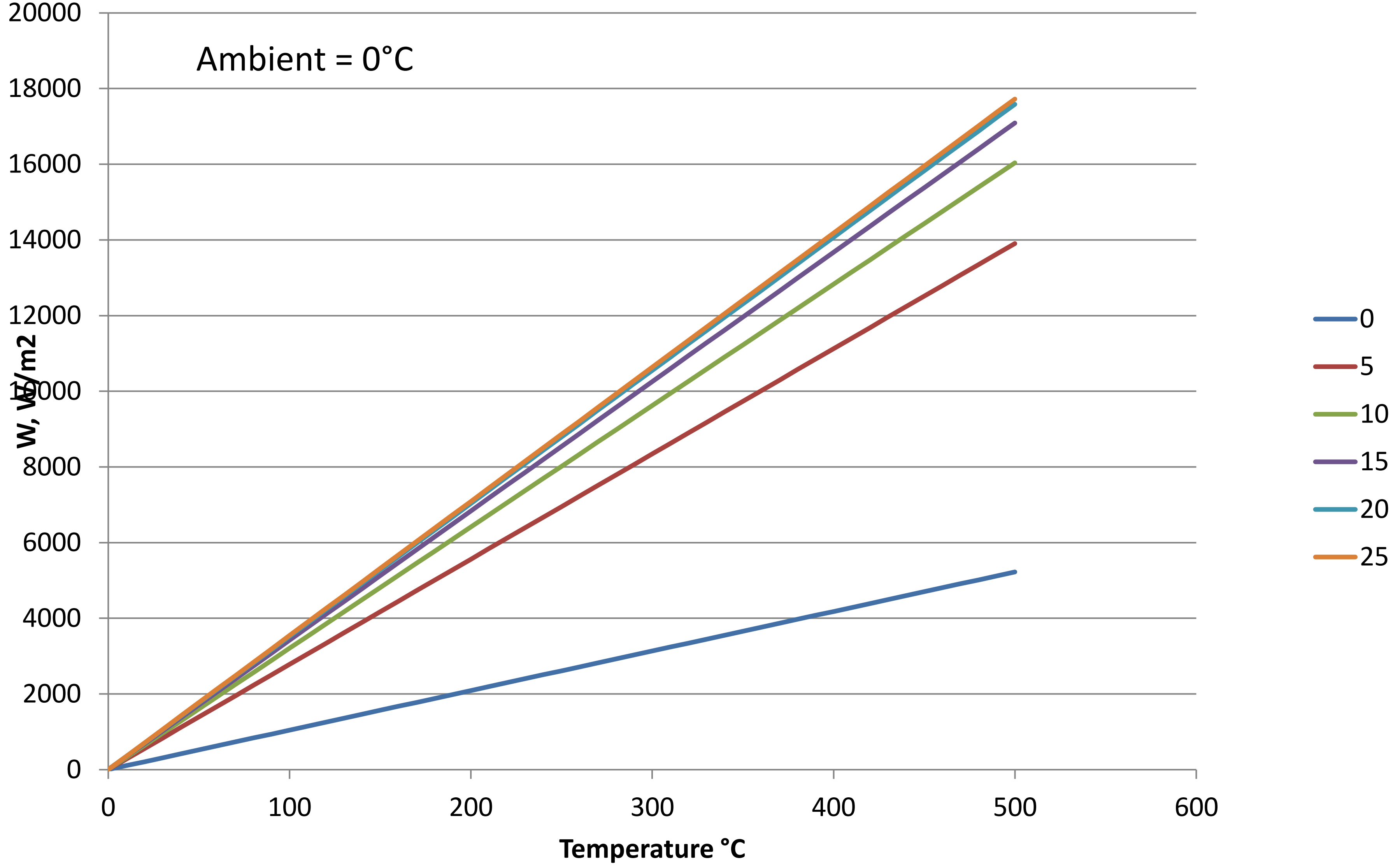
$h_c = 10.45 - v + 10\ v^{1/2}$

where v is air (wind) speed in m/s

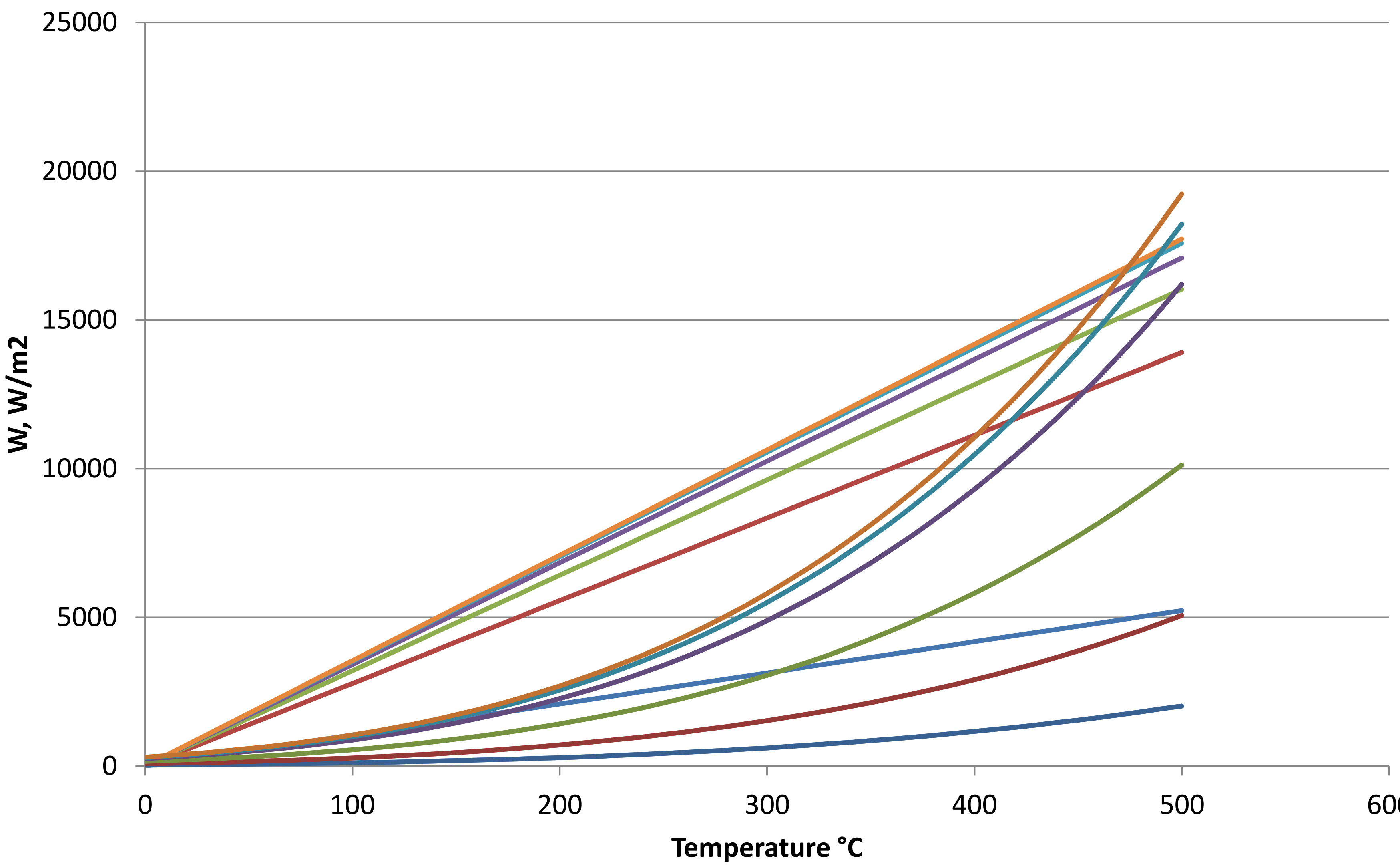
Heat Transfer Coefficient



Convective Heat Flow



Radiation and Convection



Computer Models

Designation: C680 – 10

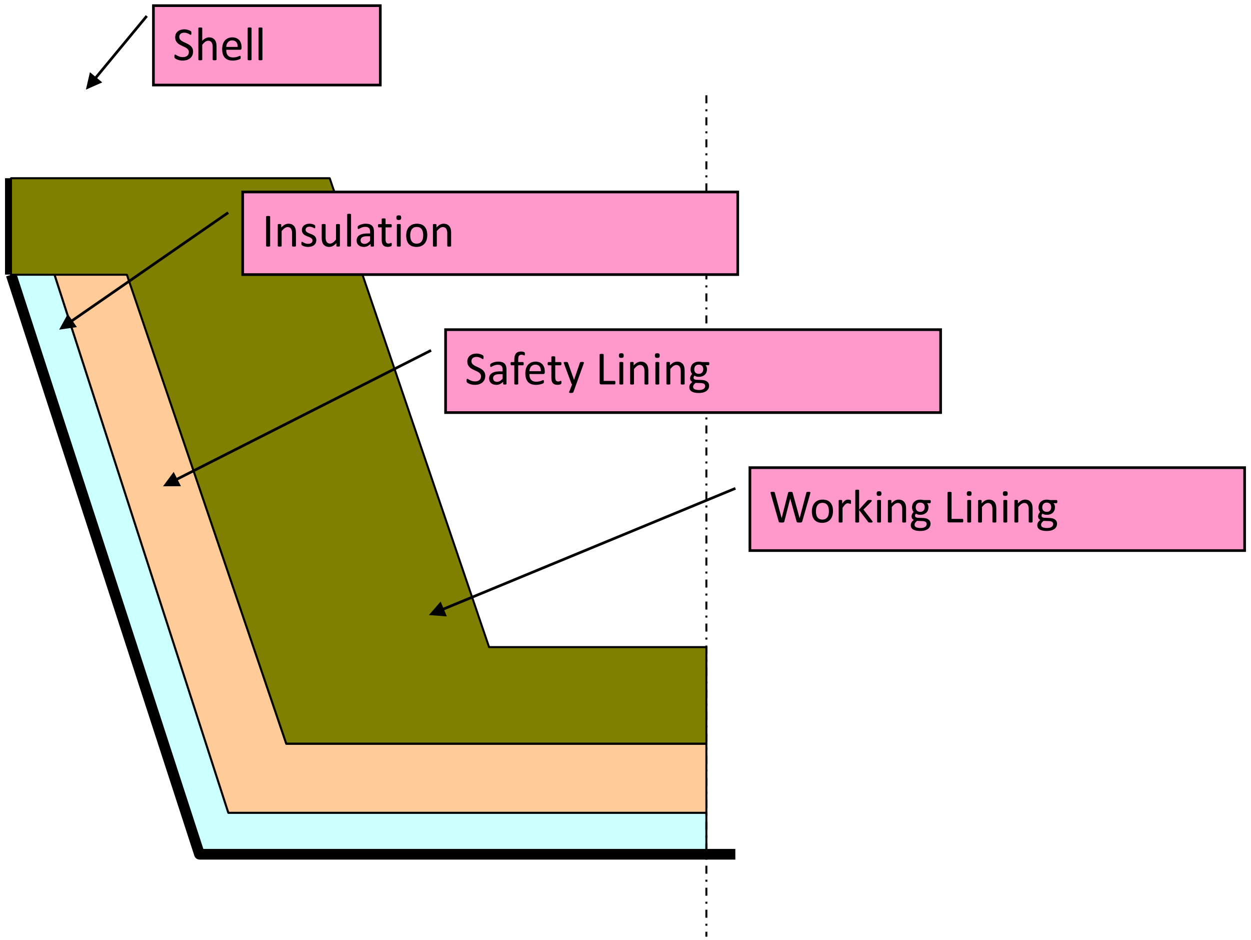
Standard Practice for
Estimate of the Heat Gain or Loss and the Surface Temperatures of Insulated Flat, Cylindrical, and Spherical Systems by Use of Computer Programs[1]

New and Worn Lining

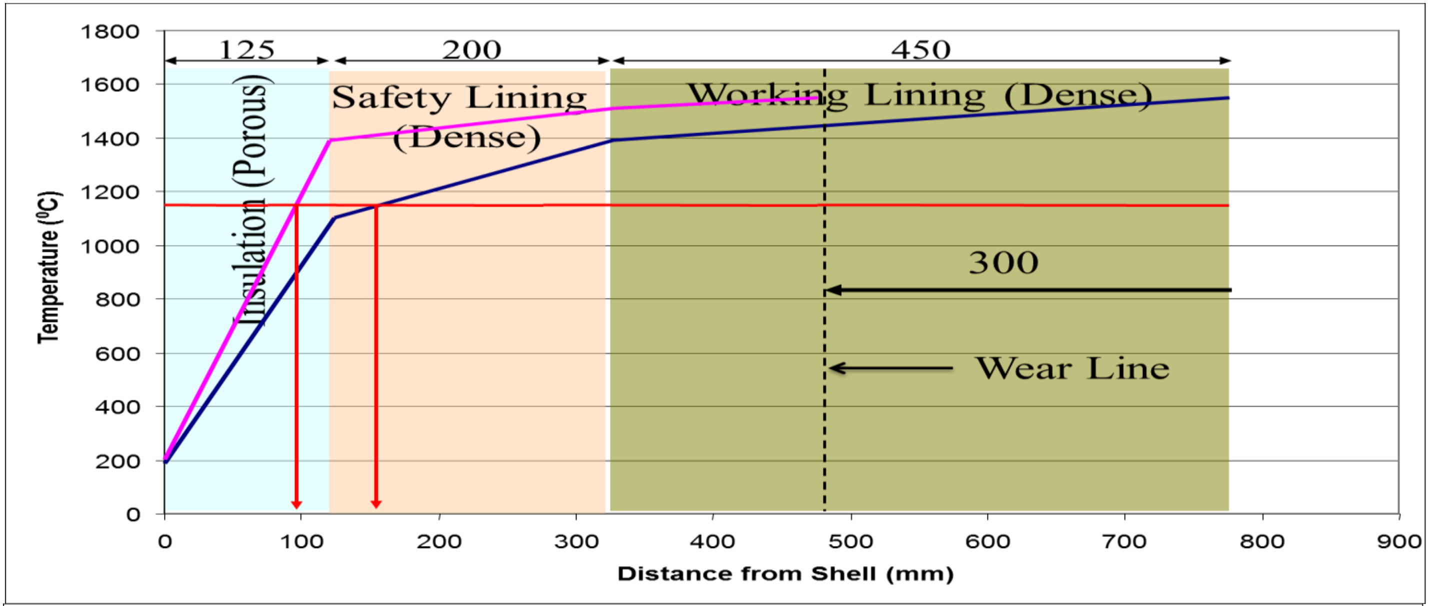
Lining is thinner when worn

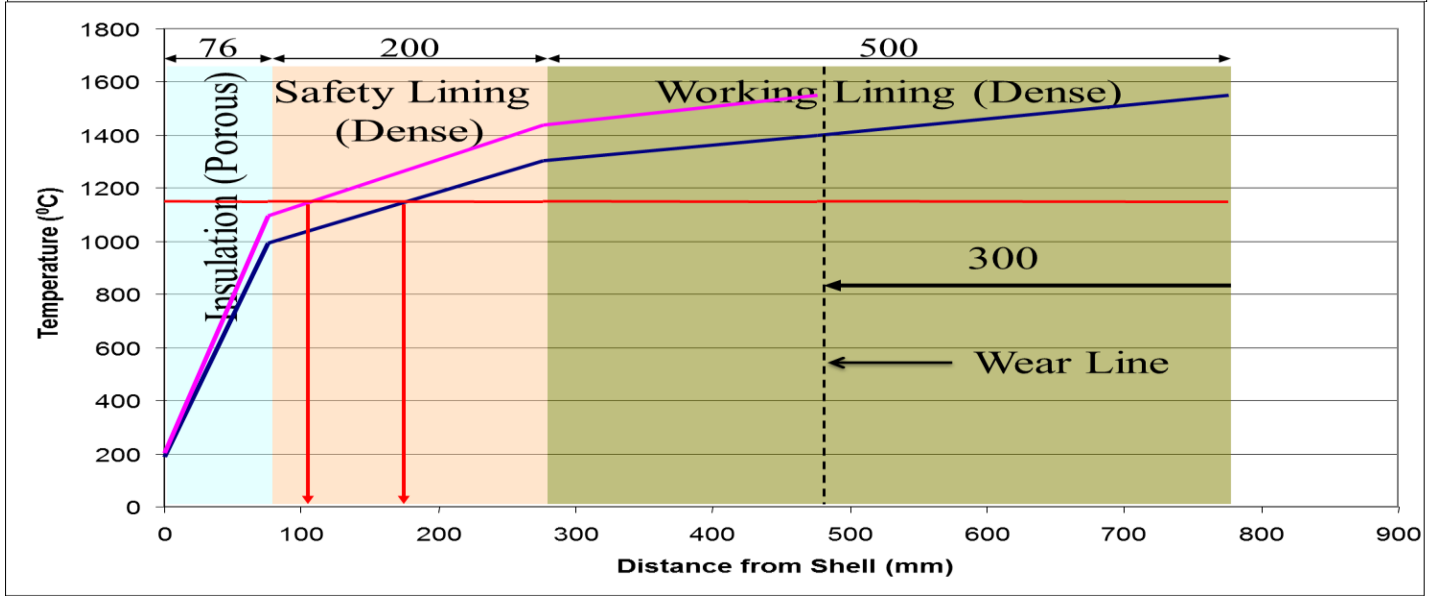
- More heat conducted
- Shell temperature will be higher
- Freeze line will be in different position

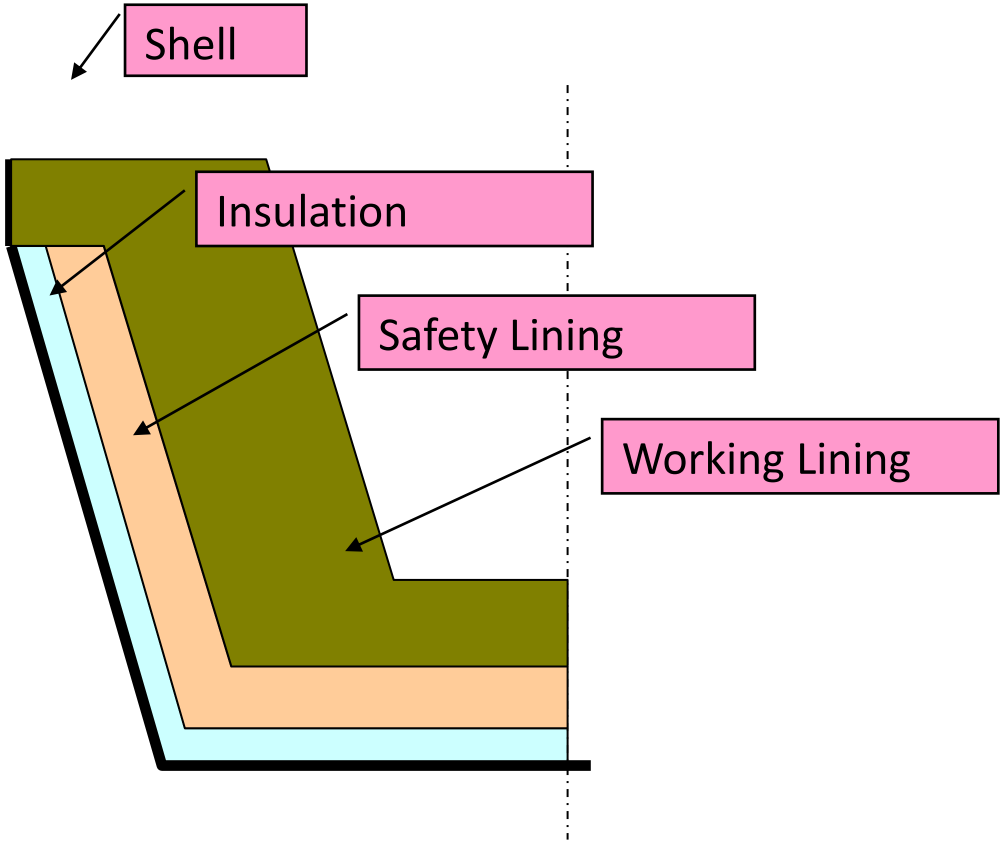
New and Worn Lining - Trough



New and Worn Lining – Trough







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Limitations

Many Limitations to this method

- Wind speed is rarely constant
- Rain?
- Sunshine?
- Surface of shell
  - Dust
  - Rust
- Does lining ever reach steady state?

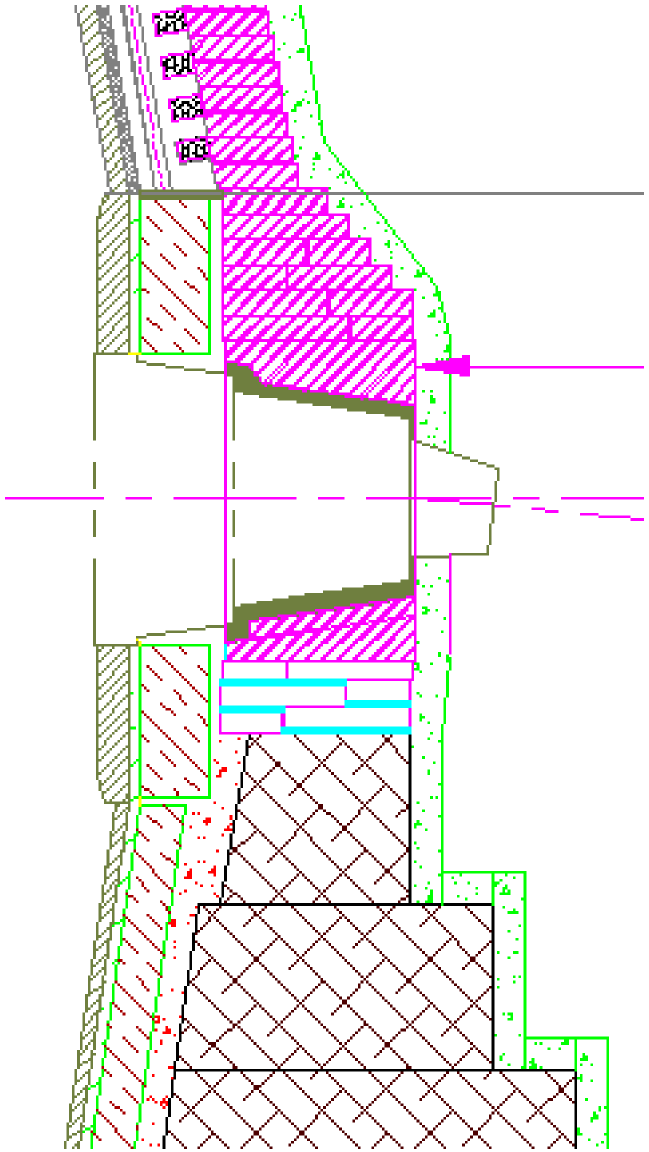
Advantages

- Quick
- Generally gives ‘worst case’ for lining design, esp for zero wind

Calibration?

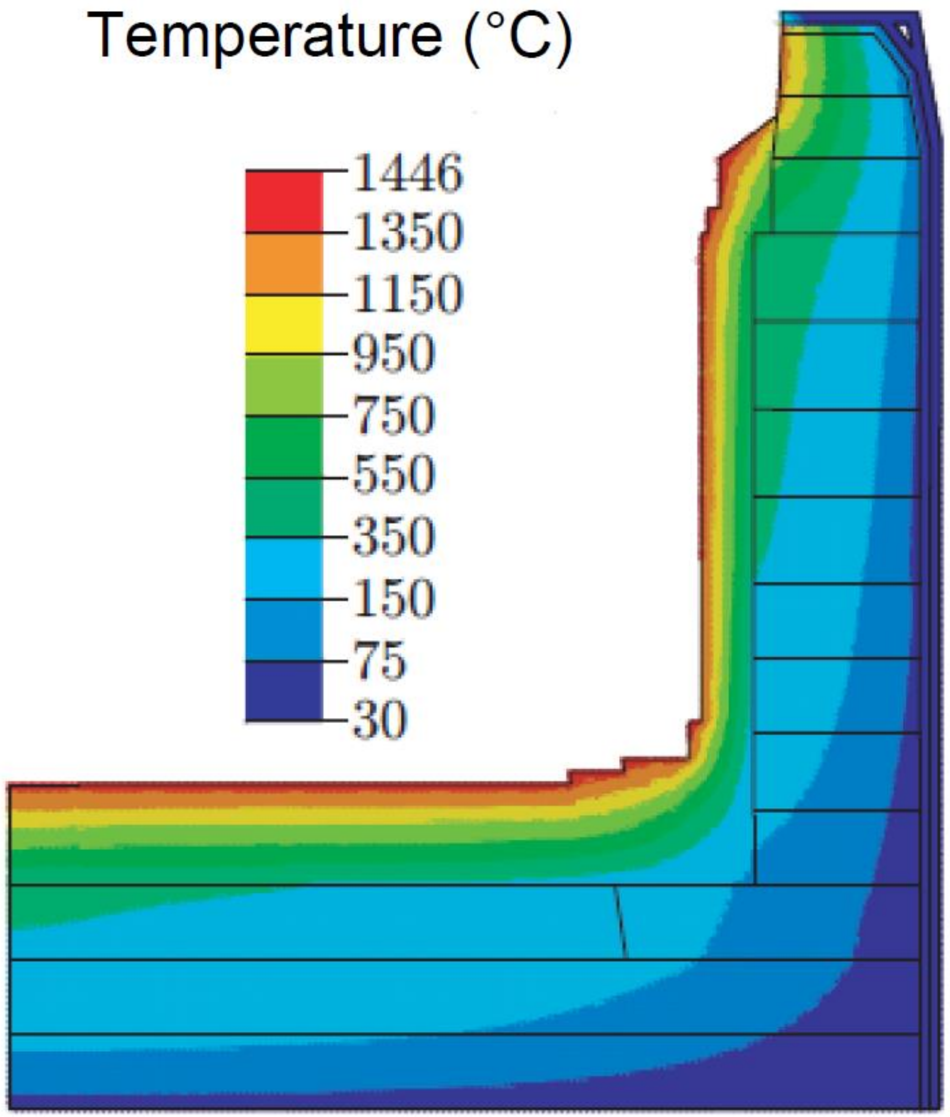
Limitations

- Can only use for simple geometry
- Plane or cylindrical walls
- Not at corners, openings, changes in lining
- Effect of anchors
- Flanges, branches etc



Finite Element Modelling (FEM)

- Thermal Profile
- Expansion Movements
- Thermal Stress



Thermal Gradient Step-by Step

1. Collect Data IN SAME UNITS

Hot Face (°C)

Ambient (°C)

Lining Thickness (m)

Lining conductivity over range of temperatures (W/mK)

Surface Emissivity (no unit)

Wind Speed (m/s)

2. First Estimate of Shell Temp – Guess
3. Find Surface Heat Transfer per sq m from graph

For Radiation

For Convection

Add together for Total

4 Calculate mean temp of lining

5. Identify Conductivity of lining at mean temp
6. Calculate temp drop across lining, ΔT from

$$W = k\ A\ \Delta T/\Delta x$$

W from step 3
K from step 5
ΔT is (Hot Face-Shell)
Δx is thickness (in m not mm)

7. New Shell Temp Estimate is Hot Face – ΔT

Calculate Shell Temp from Hot Face – ΔT

- If this is larger than estimate, your estimate is too small, try again for a larger shell temp
- If this is smaller than estimate. Your estimate is too small, try again for a smaller shell temp

7 Repeat from Step 3 until step size of change is small

Thank you

Any Questions?

https://irengineers.co.uk/