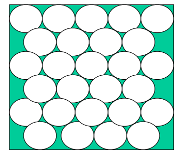
Safe and Efficient Dry-out of Castable Linings

On the left, an example of an unsafe and inefficient dry-out of a castable lining. This is the roof of a large tunnel kiln, cast in light-weight castable.

Why is there so much water in a castable?

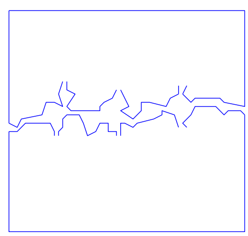


- A castable comprises grains of aggregate, cement, etc., mixed with water. Unless the grains are of infinitesimally small size, there will be water in the interstices.
- Without water (or another liquid) the castable will not flow (water acts as a lubricant).

Why do we need to heat the castable to dry it out?

- The water is happy to stay in the castable (some is chemically-bonded)
- The water will only emerge when forced to do so
- Simplest way is to boil the water, generating an increased pressure which forces the water (as vapour) out of the pores
- If the pressure becomes too high, there will be an explosion

Pore structure inside a castable



Stylised Pore channel through Castable

There is a contiguous pore structure inside a castable. After casting, these pores contain water.

Pore channels can narrow to less than a micron wide

Controlled Dry-out

- How can we generate enough pressure to force out the water but avoid an explosion?
- Heating rate too rapid→ Explosion
- Heating rate too slow →Time and money wasted

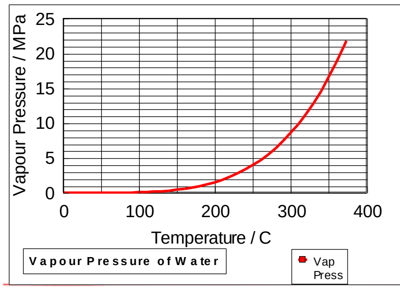
Solution to Problem

- Mathematical Model
- Heatflow to calculate temperatures
- Physical properties of castables
- Calculate water pressures
- Calculate water movements

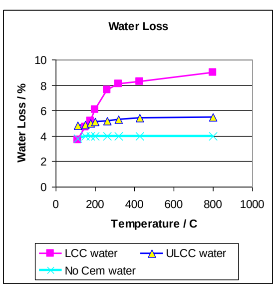
Relevant Physical Properties

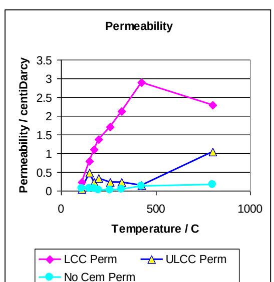
- Permeability (after heating to several temperatures)
- Thermal conductivity (at several temperatures)
- Bulk density
- Apparent porosity
- Hot MoR at 200ºC
- Free water content
- Water lost at several temperatures

Vapour pressure of water is the cause of explosions during dry-out

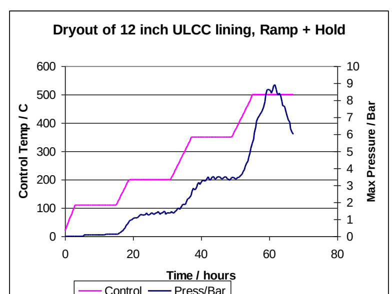


Water Loss and Permeability





Pressure in a 12 inch ULCC castable lining, Ramp-and-Hold method



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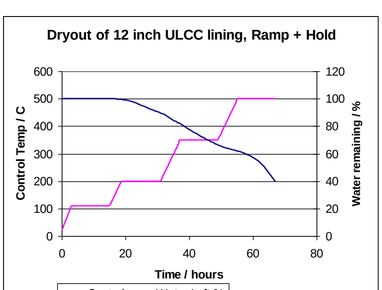
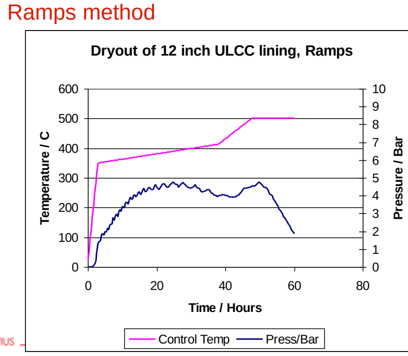
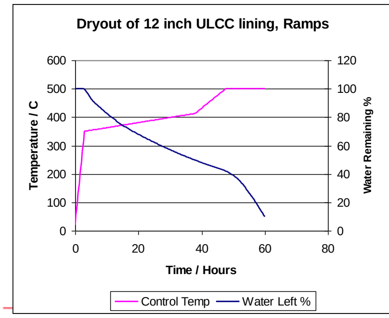


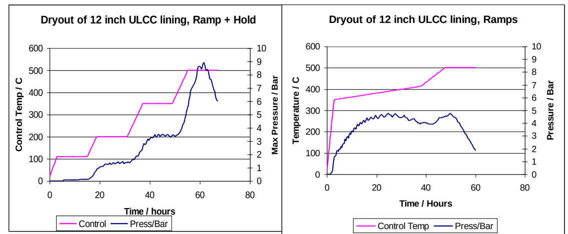
Pressure in a 12 inch ULCC Lining, Ramps method



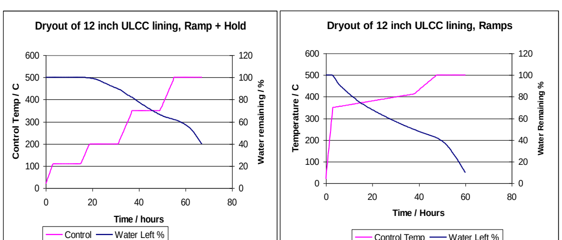
Water in a 12 inch ULCC Lining, Ramps method



Comparison; “Ramp and Hold” or “Ramps”
Pressure development



Comparison; “Ramp and Hold” or “Ramps”
Water removal



What can the model do?

- Can model one-sided dryout, and can model dryout on all sides, e.g. in drying oven
- Can calculate optimum rate by itself
- Can take into account multiple refractory layers
- Can take into account anchors and “weep holes”

Use of the Model

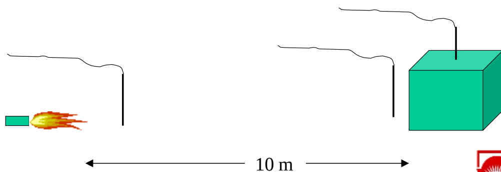
- Model has been used to solve “impossible” dryout problems.
- Large castable blocks, previously exploding even during a 6 week dryout, have been dried safely in 5 weeks
- Model is currently in use

Factors causing a Difficult Dry-out

1. Low Permeability
2. Large Block size/ Thick Lining
3. Heating from all sides
4. Low strength
5. Poor air circulation (forced circulation is good)
6. High thermal conductivity

Thermocouple Positioning

- Best thermocouple position for controlling the dryout?
  - Near the burner?
  - Inside the castable block?
  - Near the castable block?



Differences between Thermal Shock and Steam Spalling

Thermal Shock

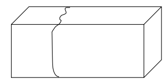
- Worse with corners
- Typically worse between 300ºC and 1000ºC
- Cracks run parallel to hot face

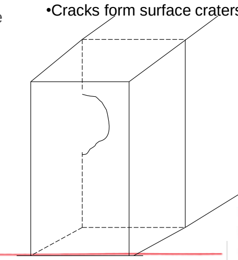
Steam Spalling

•Worse with Flat Faces

•Low temperature problem

•Cracks form surface craters





How fast can monolithics be dried out?

In favourable circumstances, quite rapidly.

Gunned ladle lining, 150mm thick, with cellulose/propylene fibres, could perhaps be heated from wet to 1600ºC in 24 hours.

In difficult circumstances, drying time can be quite long.

600mm cubes of dense, no-cement castable, heated on all faces required a drying schedule of 5 weeks

How can this be predicted without using complicated software?

Mainly from experience, but there are some guidelines

- For most monolithics, 180ºC is safe. Unless special curing is required, go straight to 180ºC. Don't mess about at 120ºC.
- Hold periods achieve very little
- Permeability and lining thickness are very important. With low permeability or thick linings, heat slowly between 180ºC and 500ºC.
- Large blocks (eg arc furnace delta) are very difficult

Measuring Permeability to Air

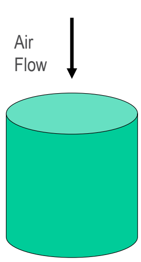
This is quite complex and values are never quoted. Very few people know much about permeability

UNITS

centiDarcy, m^2 ,	1 cD = 1 x 10^{-14} m^2
Granite	0.00001 to 0.0001 cD
Limestone	0.001 to 0.01 cD
Sandstone	0.1 to 1 cD
Ultra-Low Cement Castable	0.1 to 10 cD
Sand (Silt)	1 to 1000 cD
Low Cement Castable	1 to 10 cD
Gunning Materials	5 to 100 cD
Lightweight Castable	10 to 1000 cD

Measuring Permeability

- Air Flow



<u>Measure</u>

•Pressure difference

•Air flow

•Dimensions of test piece

<u>Difficulties</u>

•Avoiding leakage

•Measuring very low flow rates

Measuring Permeability

- Permeability is part of the proportionality constant in Darcy's law which relates discharge (flow rate) and fluid physical properties (e.g. viscosity), to a pressure gradient applied to the porous media:
- Therefore:

$$v = \frac{\kappa}{\mu}\frac{\Delta P}{\Delta x}$$

- where:

$$\kappa = v\frac{\mu \Delta x}{\Delta P}$$

  - ν is the superficial fluid flow velocity through the medium (i.e., the average velocity calculated as if the fluid were the only phase present in the porous medium) (m/s)
  - κ is the permeability of a medium (m^2)
  - μ is the dynamic viscosity of the fluid (Pa·s)
  - ΔP is the applied pressure difference (Pa)
  - Δx is the thickness of the bed of the porous medium (m)