On cyclones, build-up and up-grades
Kiln-Calculator Interface Issues

- High CO, NOx emissions;
- Calciner build-ups;
- Ring/ball formation in the kiln;
- Higher stack gas temperatures (Kcal/kg clinker).
Separating Particles from gas Flow

- In preheater/precalciner kilns raw-feed is pulverised (Ave. D 40um).

- The role of cyclones is to separate meal particles from the combustion/calcination gas products, as feed and the gas products move in the opposite direction.
Lighter particles are separated from the heavier ones: as lighter particles are entrained by the air.

It works even in the darkness!!

No wind, no problem!!
Particle and Gas Separation Mechanism

- Particles in a swirling flow will move outwards by centrifugal force:
  - heavier particles will move farthest
  - and will move downwards by gravity and drag by the outer vortex flow
- higher swirl increases capture efficiency but also increases pressure drop

- Particle entrainment from outer vortex to inner vortex
  - dip tube length; re-circulation centre & inlet duct height
Particulates’ Collection Efficiency

The Cyclone Operation: (1) Collection efficiency and (2) Pressure drop:

**Collection efficiency:**

\[ \eta = \frac{S_{out}}{S_{in}} \]  
(where ‘S’ stands for solids)

**Pressure Drop:**

\[ dp = \left( \frac{V}{D} \right)^2 \]  
(where V and D are the cyclone inlet velocity and diameter)

• So increasing cyclone’s inlet velocity or reducing its diameter would increase the collection efficiency but it would increase its pressure drop too.

• High-efficiency cyclones with low pressure drop result in lower fuel and power consumption.
Dropout chamber (Tertiary air take-off from the kiln-hood)

Base design
Conical deflector plate
Flat plate deflector
Extended flat plate deflector

Loading:

<table>
<thead>
<tr>
<th></th>
<th>Air</th>
<th>32x10^4 m3/hr, 950 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>7.5</td>
<td>t/hr</td>
</tr>
</tbody>
</table>

Size distribution (%):  

<table>
<thead>
<tr>
<th></th>
<th>100 µm</th>
<th>200 µm</th>
<th>500 µm</th>
<th>800 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>10</td>
</tr>
</tbody>
</table>
Midlothian Dropout chamber Poor Performance Issues

Base design

Outlet

\[ \eta_{\text{bot}} = 63\% \]
\[ \Delta p = 0.6 \text{ mbar} \]

Implemented design

\[ \eta_{\text{bot}} = 78\% \]
\[ \Delta p = 1.7 \text{ mbar} \]

Conical deflector

\[ \eta_{\text{bot}} = 87\% \]
\[ \Delta p = 1.0 \text{ mbar} \]

Extended plate deflector

\[ \eta_{\text{bot}} = 98\% \]
\[ \Delta p = 2.6 \text{ mbar} \]
Leamington Plant, Ash Grove Cement, US

• The Problem:
  • Poor particle separation efficiency of stage 4 cyclone and build-up problems.
Build-up in Stage 4, Calciner at Leamington Plant, Ash Grove Cement

Kiln Gases
94.49 tph @ 1630 ºF

CO₂ 19.28%
H₂O 5.92%
O₂ 3.50%
N₂ 71.30%

Stage 3 Meal
179 tph @ 1322 ºF
Velocity 1380 fpm

Tertiary Air
95.24 tph
1450 ºF
The asymmetricity of the recirculation zones prevails
Exit Temperature
1660 °F

Sever Build-ups
Oxygen Mass Fraction [-]
Pressure difference in the calciner is about 2" compared to 3" measured, while that between calciner and the stage 4 cyclone exit is about 4.4" compared to 6" measured.
Meal Particle Trajectories

Some particles going down and getting collected

Some particles going up through the exit duct
Particle Trajectories

All Particles
Collection Efficiency 70%
Poor collection efficiency results from the fact that some flow short-circuits to the exit duct without going down inside the cyclone. This carries some particles directly to the cyclone duct.

- Project recommendations to make connecting duct longer so that flow fully develops before entering into cyclone (i.e., 5 duct diameter distance)
- Resizing of the stage-4 cyclone, and changes to lower riser duct resulted in smooth flow pattern with an increase in throughput.
Meal Spillage
Meal Drop-through

What is it?
“Meal particles short circuit a preheat stage and drop straight into the kiln hearth area.”

The cause:
- Low upwards velocites of gas near to the meal inlet;
- Meal particles agglomeration due to inefficient heat transfer or high alkali –Cl and SO₃;

Meal Spillage problem is worse when the clinker production is reduced!! Why?
Meal Drop-through

Consequences:

• kiln thermal consumption increases;

• Higher cyclones / gas riser temperatures - hence potential for build-ups;

• (Hot) Meal spillage from the kiln feed-end (health safety issues – hot-meal flows like water!!)
Meal Drop-through
Velocity field - Gas riser

100% Load (clinker production)
Gas riser velocity: 30 – 25 m/s

50% Load
Gas riser velocity: 15 – 12 m/s
Meal Particles Tracking: 100% Load

45 µm
90 µm
200 µm
500 µm
1000 µm
1.7 m
1000 µm
Meal Particles Tracking: 50% Load
Velocity Field

Potential for meal drop through will look at this in more details after the burner work has been done.
Even at 100% kiln production velocity are lower but at lower production upward velocity goes down to @ 7 m/s near to the meal inlets;
Meal Particles and DFS Trajectories at 50% Load

Increase on size of meal agglomerated

μm scale

mm scale
When meal particles do not spread due to splash box inefficiency they behave like a dense phase of meal agglomerates which goes down and near to the wall for some distance until be spread by upwards flow.

Meal agglomerates keeps in micron scale size they can be captured by the recirculation zone but even in that case upward flow will be able to spread that small agglomerates and revert its trajectory to the upward direction.

But some bigger agglomerates in the millimeters scale can also be formed by meal particles.

Meal agglomerated will drop and be carried by hot meal to kiln seal region.
The Insert Design

<table>
<thead>
<tr>
<th>Position</th>
<th>Original</th>
<th>Insert I</th>
<th>Insert II</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.65</td>
<td>3.65</td>
<td>3.65</td>
</tr>
<tr>
<td>B</td>
<td>3.65</td>
<td>3.35</td>
<td>3.07</td>
</tr>
<tr>
<td>C</td>
<td>3.65</td>
<td>3.65</td>
<td>3.65</td>
</tr>
<tr>
<td>L</td>
<td>-</td>
<td>1.78</td>
<td>1.78</td>
</tr>
</tbody>
</table>
Due to the insert an increase in upwards velocities from @ 7 m/s in original geometry up to @10 m/s in insert I and to @ 13 m/s in insert II geometries.
Meal Particles and DFS Trajectories at 50% Load

From this point meal agglomerated will be carried by hot meal to kiln seal region.

Both inserts promote increase on upwards velocities near to meal inlets and also in the gas riser. Hence big agglomerates' spreads and its trajectories are reverted to the upwards direction.

Estimated Increase in pressure associated with Insert II is \(< 1\text{mb}\) at 100% Load.
The Role of the Splash Boxes
HOLCIM Splash Box Design

Correct

Wrong
Splash Box Design
The Tertiary Air is going through the common ducting before the split. One arm is longer than the other and are connected to the main body of the calciner (cylindrical part) East and West sides.
Velocity variation through Tertiary Air ducts

WEST Side: 60% of mass

EAST Side: 40% of mass

Velocity Magnitude

Plane in the middle
Build ups in the tertiary air inlet

View from inside of T.Air

This has been scraped from the rest of the TA inlet

Meal Inlet

Deposit

View from inside of T.Air

Deposit
TA wall attrition with dust and other particles
Gate for flow adjustment / Stuck! (There goes the flow symmetry)
CC Chamber TA Blockage
Meal Particles’ Residence time (s)
Clinker Particles (Fine Particles)
Clinker Particles (Average Particles)
Possible Solutions!

Current Arrangements
Possible Solutions! (1)

Shifting Hot Meal pipe by 100 mm closer to chamber
Possible Solutions ! (2)

Extending the injection pipe inside the arm body with a possible addition of a splash plate fitted at the end.
Adopted Solutions

Combination of 1 and 2; shifting the pipe by 1 m and extending it with a splash plate fitted at the end.
Plugging issues (SO3 cycles)
How Do the Plants Operate?

• Most cement plants take Molar Ratio of 1 (MR, sulphur over Alkalis, as an indication of build-up potential),

• Whereas as excess SO3, when allowing for Cl in the hot meal is the key factor!

• Where VF is SO3 hot meal/SO3 clinker

• Even for a 2% SO3 in clinker (usually maximum targeted value) the hot meal will be 4% (SO3), which is not easy to manage – (N.B.) some plants operate at 5% SO3 and 2% Cl)
  - via:-
  • Blasters
  • Splash Box
  • Meal Curtain
  • SiC
Some CINAR 2010 Clients Plants Blasters plus poking and prodding needed Problems begin OK

Big buildups high Cl from AFR No AFR YET, but already potential SO3 issues

Hot meal SO3 %
Build-Ups Monitoring during 3 Years

High Build-ups

Low Build-ups
Low Capex approaches to preheater and kiln optimisation for increased output (up-grades)
Why use Cinar?

• Low-cost solutions, minimum modifications to the calciner (usually savings of 2-4 M€ - including the plant down time), hence very attractive!!

• Flexible solutions (making use of existing equipment and integrating innovation)!!
Objectives of MI-CFD

- **Tracim** plant have taken measures to upgrade its clinker production from 6000 to 6500 tpd.

- During a visit to the plant some measurements have shown higher temperatures in the West side of the Calciner in the near TA inlet region, which has also resulted in refractory failure. Hence two Base Cases were simulated to understand those fluid thermodynamics which cause the ‘hot-spots’ on the West side of the calciner duct.
Increased Production (II)

Aerodynamics - Velocity magnitude (m/s)

Large velocities observed above 60 m/s locally at the restriction.

60 m/s locally at the restriction.
Pressure drop

The restriction increases the pressure drop for 6000 tpd case and it will increase further at higher production rates.
Final kiln inlet design: (Balanced Tertiary Air ducts 6500 or 7000 tpd)

- **Base Case**
  - Velocity >60 m/s

- **Modifications to Kiln inlet**
  - Velocity 40 m/s
  - Velocity 30 m/s
  - For Pressure reduction 3-5 mbar

To be implemented in 2017
Two upgrade projects with PMT
Cinar-pm Technologies

- Process Analysis - Cinar
- Combustion/Process Modelling - Cinar
- Engineering, Commissioning and Installation – pm Technologies
- Tailored Solutions – Cinar & pm Technologies

Low Capex!!
The Up-grades

Generally, with ID fan capacity available, the Plant ‘OUTPUT’ is dictated by the commonly accepted limits:

Cooler area – 40-60 tpd/m²
Burner zone thermal Load – 6 MW/m²
Cyclone cross section - 100-120 tpd/m²
Kiln Volume loading - 6 tpd/m³
Kiln Fill – 10%
The velocity at the pinch point - < 30-35 m/s
Kiln Burner – 7-10 N/MW

Calciner Burner(s) – No fixed criteria
Case Study I - (2011/12)

ILC - CALCINER KILN UPGRADE

REFERENCE Venezuela
PROJECT OBJECTIVES

- To increase clinker production from 2,880 to 3,200 tpd

- Limiting factor: Short kiln (49 m kiln length; 4.2 m steel kiln diameter)

- So to increase the output, calciner had to be operated at the best calcination level – for low Capex – without having to add extra volume (for gaining extra RT)!!
Up-Grade (2880 to 3200 tpd)

In-line calciner kiln upgrade

GUIDE VANE installed at dip tubes

Steel parts manufactured in Europe

30 days dismantling and erection time incl. refractory lining work
KILN/CALCINER UPGRADE

- Stage 1: High efficiency cyclones incl. guide vanes HURRITEC GV
- Stage 4: Staged meal chute system installed
- Stage 5: Cyclone entrance bend modification
- Preheater accessories (Meal splash boxes, pendulum flaps etc.)
- In-line calciner optimisation:
- Calciner Burner and calciner meal feed re-positioning, increased retention time (+0.5s), TA inlet modification
MI-CFD Computational Model

Outlet

Tertiary Air Inlet

Kiln Inlet
Geometry and Dimensions

4 Gas Burners
2 Oil Burners
1 Meal Inlet
Upward Velocity

Higher Velocity Regions

Lower Velocity Regions

Higher and lower oxygen regions show highly stratified flow

Velocity m/s (Upward)
45
40
35
30
25
20
15
10
5
0
-5

Oxygen

Temperature °C

0.23
0.207
0.184
0.161
0.138
0.115
0.092
0.069
0.046
0.023
0

Temperature

Hot spot - highest temperature regions (in red) are created above TA volatiles/oil droplets combust in the absence of meal particles
Optimised Case: Additional Meal inlet & NG burners relocation

Exit Temp.: 895°C
Calcination: 98.1%

Single Meal inlet
(Before)

Hot spot in the absence of the lower meal
Up-Grade Results (in operation since April 2012)

- **RT = 4.6 sec**
- **RT = 5.1 sec**

**Calcination**
- Before: 91%
- After: 98%

**Clinker output**
- Before: 2880 tpd
- After: 3400 tpd

Target: 3200 tpd
Case Study II - (2013/14)

Kiln upgrade to increase the output from 3000 tpd clinker to:
→ 3700 tpd in Phase 1 (Upgrade to AT calciner kiln)
→ 4200 tpd in Phase 2 (Upgrade to ILC calciner kiln with TA)

The most difficult challenge has been the structural limitations for calciner upgrade!
The AT Calciner Phase I:

- Oil Burners = 2
- Meal Inlets = 4
- Outlets = 2
- Bypass = 1

Diagram showing:
- Meal Inlets
- Modified inlet locations
- Oil Burners
- Bypass Outlet
- Kiln Gases Inlet

Diagram with annotations showing flow and connections.
Phase-I Solution

Lower meal inlets moved above oil burners to avert meal particles from trapping in the low velocity regions.
Phase II BC: Geometry and Inlets
Phase II Optimisation: TA Relocation

30% 35% 35%

Outlets
Flow Biasness – Stream Lines from Kiln Inlet

A flow asymmetry caused by the riser duct geometry forces more flow to go into the left arm (A) Relatively higher temp. B

Bypass

Lower TA Case

A 932 °C

B 808 °C

BC
Phase II: Oil burner relocation

Un-optimised Case

Optimised Case (Riser Burner, moved slightly right (0.5m))
Phase II Results – Temperature Profile

<table>
<thead>
<tr>
<th></th>
<th>A 932 °C</th>
<th>B 808 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>A 864 °C</th>
<th>B 876 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**AT Calciner operating at 3800 tpd (on average) - since April 2014**

<table>
<thead>
<tr>
<th>PLANT DATA</th>
<th>BEFORE MOD.</th>
<th>PHASE 1</th>
<th>PHASE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of kiln system</td>
<td>SP kiln</td>
<td>AT calciner kiln</td>
<td>ILC kiln +TA</td>
</tr>
<tr>
<td>Clinker output (tpd)</td>
<td>3000</td>
<td>3700 (+23%)</td>
<td>4200 (+40%)</td>
</tr>
<tr>
<td>Thermal fuel split (%)</td>
<td>92 / 8</td>
<td>75 / 25</td>
<td>50-60 / 50-40</td>
</tr>
<tr>
<td>Calcination (%)</td>
<td>52</td>
<td>&gt;76</td>
<td>&gt;85</td>
</tr>
</tbody>
</table>

**Calciner output**

- Before: 3000 tpd
- After: 3700 tpd (+23%)

**Calcination**

- Before: 52%
- After: >76%
- >85%

**Thermal fuel split**

- Before: 92 / 8%
- After: 75 / 25%
- 50-60 / 50-40%
The Better Understood, the Better Solution!!