How FCT's modelling and process expertise helped a European cement plant improve their alternative fuel firing substitution rate

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ABOUT THE CLIENT
Cemmac operates a 5-stage ILC kiln (3.4m x 46m long), which produces 1,200t/d of Portland clinker.

At the time of the study, coal and Residue Derived Fuel (RDF) were fired in the kiln by a 30MW burner from another supplier based in Europe. Additionally, 2 calciner burners, from that same supplier, were used to fire coal in the calciner. Tyres were also fed to the kiln inlet and RDF to the calciner at the twin tertiary air inlets.

THE SITUATION
Cemmac approached FCT Combustion as they wished to increase their alternative fuel substitution rate.

The rate of RDF firing in the calciner was limited to 20% due to high CO levels, measured at the exit stage 4 cyclone (with stage 5 being the bottom stage) in excess of 0.3% or 3,000ppm. Even when firing 100% coal, the firing rate was limited by CO which in turn limited the degree of calcination and overall plant capacity (LOI of the stage 5 hot meal high at 8.4%).

Severe problems with build-up forming in the area above the kiln inlet chamber were also identified. To remove the build-up, the kiln was stopped for several hours roughly once every two weeks.

A process and combustion study of the kiln, as well as a more detailed Computational Fluid Dynamics (CFD) study of the calciner, were undertaken to:

- Improve coal combustion
- Improve RDF combustion
- Reduce CO levels in kiln inlet
- Increase alternate fuel substitution
- Consider introducing a new alternative fuel, Polyurethane (PUR) dust, to calciner
- Reducing build-up in the kiln system
- Improve operational stability

FCT was established more than 35 years ago to bring more science into the art of industrial combustion.

Since then we have gained a reputation for technical excellence and introducing innovative, value-adding technologies for high temperature processing industries.

Kiln and calciner burner systems have a major impact on the bottom-line results for a cement plant, and so customised optimisation of the flame for any given kiln is critical to get the best plant performance.

We are combustion experts with a strong history of using various types of modelling to optimise burner designs and deliver performance.

PROCESS EVALUATIONS
Process evaluations of sulphur and chloride build-up in the system can be seen in Figure 1 and Figure 2.

For a kiln with favourable operating conditions, the volatility of SO3 in the kiln would normally be in the range 0.3 to 0.5, but Cemmac was averaging around 0.85.

WHY WAS $\text{SO}_3$ VOLATILITY ($\phi$) SO HIGH?
The volatility of $\text{SO}_3$ is dependent on the form that the $\text{SO}_3$ is in ($K_2\text{SO}_4$, $Na_2\text{SO}_4$ or $Ca\text{SO}_4$) and the operating conditions of the kiln and increases with:

- An increase in localised reducing conditions such as flame impingement and fuel in the clinker bed
- A reduction in oxygen levels in the kiln (giving global reducing conditions)
- An increase in the sulfur/alkali balance above 1 (in the kiln system inputs)
- A reduction in the clinker granule size (easier diffusion to the granule surface)
- An increase in the maximum burning zone temperature
- An increase in the retention time in the burning zone
**FIGURE 1**
PROCESS EVALUATIONS
Sulphur and Chloride build-up in system

Red lines indicate normal volatility range

\[ \varphi_{SO_3} = 1 - \frac{SO_{3,CL}}{SO_{3,HM}} \]

**FIGURE 2**
PROCESS EVALUATIONS
Sulphur and Chloride build-up in system

**FIGURE 3**
PROCESS EVALUATIONS
Sulphur/Alkali ratios

HOT MEAL - SULFUR BALANCE
\[ \frac{[SO_3/80]}{K_2O/94+Na_2O/62-cl/71} \]
DESIRABLE RANGE (0.7 - 1.2)

**FIGURE 4**
PROCESS EVALUATIONS
Sulphur/Alkali ratios

SULFUR BALANCE (SO3/80) /
(K2O/94+Na2O/62-CI/71)
FIGURE 5
CHEMICAL FACTORS

FIGURE 6
CHEMICAL FACTORS

FIGURE 7
CHEMICAL FACTORS
Clinker burnability - LSF vs SR

FIGURE 8
CLINKER PROPERTIES
Clinker %Liquid Phase or %Flux at 1450°C
WHY IS %CI SO HIGH IN HOT MEAL?
Cl is high in hot meal because the input is higher than the output, accumulating in the kiln at a rate of approximately 18kg/h. Cl input from the raw meal, coal, tyres and RDF as a percentage of the raw meal is 0.098%.

The Cemmac kiln has a chloride bypass for removal and control of chlorides within the kiln. Cemmac bypass is only sized for ~4%, however the rough ‘rule of thumb’ for sizing of a Chloride bypass is:

%Kiln Exit Gas Bypassed = %Cl of the raw meal on LOI free basis x 100.
%Bypass Required for Cemmac = %0.098 x 100 = 9.8%.

CONCLUSIONS FROM PROCESS STUDY
• There are excessive amounts of sulphur and chloride in the hot meal that will lead to build up and operational instability.
• There is excessive volatilisation of sulphur from the clinker that leads to this.
• There is nothing unusual with the clinker chemistry or granulometry that gives rise to this – sulphur/alkali ratio of the clinker is quite low.
• The burner momentum is quite high – so increasing burner momentum will not improve the retention of sulphur in clinker.
• AF fuel particles are falling on the clinker bed and most likely the cause of the sulphur volatilisation, but there is probably a flame shape issue as well.
• Adding Gypsum into the raw meal is making the situation worse – why is gypsum added?
• The chloride bypass in undersized for the amount of chlorine in the system and should be increase to 10% to cope with current levels of chlorine.
CALCINER & CFD MODELLING

The rate of combustion of each solid fuel is controlled by:

- The chemical composition of the fuel itself,
- Particle size and shape, and
- The aerodynamic trajectories that the fuel particles follow.

REQUIREMENTS TO ACHIEVE BURN OUT OF SOLID ALTERNATIVE FUELS IN CALCINER

TIME
Calciner retention time ↑by:
- ↓AF size
- AF 3D → 2D
- ↓Gas velocities
- ↑Calciner volume

TEMPERATURE
- ↑Temp = ↑Rate of AF combustion
- CaCO₃ → CaO + CO₂ = ↓Temp

SIZE/SHAPE
↑Rate of combustion & ↓Retention Time by:
- ↓AF size
- AF 3D → 2D

OXYGEN/ MIXING
Rate of AF combustion ↑ by:
- ↑O₂
- ↑Turbulence/ Mixing
Some of the flue gas loops around in a small diameter
Some of the flue gas loops around in a large diameter
Some of the flue gas bypasses the mixing chamber
CFD COAL COMBUSTION: POOR COAL DISPERSION
(EXISTING CONFIGURATION)

Coal particle traces coloured by volatile mass fraction.

Mostly yellow

Mostly green

Good dispersion

Poor dispersion

Char combustion starting in the mixing chamber (blue = very little char mass fraction)

Char combustion starting before the mixing chamber (blue = very little char mass fraction)
CFD COAL COMBUSTION: IMPROVED COAL DISPERSION & COMBUSTION
(EXISTING CONFIGURATION WAS MODELLED VERSUS PROPOSED CONFIGURATION)

Coal particle traces coloured by volatile mass fraction.

- Relocated burner from front to rear
- Both burners to Level 3

-现有燃烧器
-已移动燃烧器

Coal char only begins to burn out in the mixing chamber

- 煤炭焦炭仅开始在混合室中燃烧

- Improved coal char combustion commencing lower in the calciner

- 改进的煤焦炭燃烧开始于电石炉更低处
RDF COMBUSTION:
SORTING INTO HEATING VALUE, PARTICLE SIZE & SHAPE GROUPS

FUEL GROUP 1:
LHV= 13,240kJ/kg
cf. 30,650 kJ/kg Coal

a. 2D Paper; b. 3D Wood

c. Close up of 3D wood. Even for a small wood particle (size indicated in red) the burn out time in typical calciner conditions is in the order of 15-30 seconds.

d. Experimental burn out time for a single pine wood cylinder 1.65mm diameter x 6.6mm long in an air velocity of 1.5m/s

FUEL GROUP 2:
LHV= 23,520kJ/kg
cf. 30,650 kJ/kg Coal

e. & f. 2D thin film and thick plastics

g., h., i. & j. 3D plastic, rubber & foam

REMAINING UNSORTED RDF

k. +2mm
l. -2mm
CFD COAL & RDF COMBUSTION: RDF 3D PARTICLE SIZE VS RESIDENCE TIME

Diameter <0.5cm
2-8 seconds

- Adjust quickly to the gas flow
- Follow the kiln flue gas flow path
- 2-8 second residence time
- Burnout time of many of these particles is longer than the residence time in the calciner

Diameter 1-2cm

- Bounce around more
- Some fall into kiln and have very long residence times
- Those that exit with the flue gas have 8-24 second residence time
- Burnout time greater than residence time

Diameter >2cm

- Majority fall into kiln
- Those that exit with the flue gas have ~24 second residence time
- Burnout time greater than residence time
CFD COAL & RDF COMBUSTION: RDF COMBUSTION PROBLEM SUMMARY

CONCLUSIONS FROM THE CALCINER AND CFD MODELLING

Due to the relatively large size of the RDF (cf Coal), the burn-out time was much longer than the residence time of the calciner.

The calciner is designed for coal combustion and does not have a sufficiently high solids:gas residence time ratio for combustion of the RDF within the calciner. In addition, the calciner design does not provide a high temperature zone for combustion of difficult fuels.

As a result, unburnt volatiles and char would exit the calciner and continue to burn, emitting CO which was then detected by the gas analysis system, limiting the fuel firing rate. In addition, unburnt char was collected in the bottom stage cyclone and entering the kiln with the hot meal, causing reducing conditions.

Whilst relocating the coal burners improved coal combustion, it made little improvement on RDF combustion. A number of changes were made to the CFD model to try and address issues such as raising the temperature and improving the heating value, but none made sufficient improvement to justify the change. The changes included:

- Increasing the tertiary air temperature by 100°C (from 950 to 1050°C).
- Raising the meal feed pipe entry point to produce a high temperature zone below the meal entry point and accelerate RDF and coal combustion.
- Reducing the RDF moisture (from 17.5 to 10%) to reduce the drying time and improve the LHV.

As an example, raising the meal entry point had the desired effect of raising the temperature but was still insufficient to ensure burn-out of the RDF.
As discussed, the biggest problem with the RDF was its large size. A new dusty alternative fuel injected through the coal burners was modelled. The alternative fuel dust has both a very fine particle size and good heating value.

Three alternative fuel dust firing cases were modelled:
- 100% replacement (3.25t/h PUR)
- 36% replacement with the remainder 64% coal (1.26t/h PUR and 1.64t/h coal); and
- 36% replacement with the remainder coal 46% and RDF 18% (1.26t/h PUR, 1.17t/h coal and 0.8t/h RDF)

In all cases, alternative fuel dust and coal combustion was good but there was no change to RDF combustion. With the use of alternative fuel dust, it is important that the total input of Chlorine to the kiln has been considered.
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS FROM CFD STUDY
Re-location of the coal burners to the low velocity region on level 3 would provide a marked improvement in coal combustion in the calciner. There is also improved combustion from smaller 2D particles of the various alternative fuels used. However, the 3D particle combustion is not improved significantly by a relocation of the burners - the particle shape/size is the problem.

Multiple burners, increasing the tertiary air temperature, reducing alternative fuel moisture, and creating a high temperature zone were also modelled and likewise provide only a marginal improvement in the combustion of alternative fuel 3D particles. For improved combustion of these particles, either the calciner residence time must be increased, the alternative fuel particles must be limited to 1mm maximum in any dimension, or some other novel design be considered that allows more time for particle burn-out.

RECOMMENDATIONS
• Much of the sulphur volatilisation was arising from the kiln burner flame shape and impingement. It was recommended that this be addressed so that the sulphur content of clinker can be increased to normal levels, as well as to reduce the build-up being experienced.
• Calciner burners should be relocated to the level 3 low velocity region of the calciner.
• The practice of adding gypsum to the raw meal should be stopped if possible.
• The chloride bypass should be increased to 10% (from 4%) of kiln gases.
• The alternative fuel dust is a good option and as much of the RDF as possible should be replaced with this.
• Reduce RDF particle sizing further if possible.
• Consider calciner enlargement options to increase residence time.

Stay tuned for the next edition of the FCT Combustion newsletter, ‘Burn After Reading’, where we will include the next part of this case study addressing burner design and selection.
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