Converting a calciner from oil to natural gas firing: enabling fuel savings through CFD modelling

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Introduction

Natural Gas (NG) can be an attractive fuel due to its high heating value, low carbon emissions, no need to stockpile, store, blend, grind or preheat, and, in some regions, low price. However operationally its use can cause challenges due to its high ignition temperature, high flue gas volume and low heat transfer when compared with liquid and solid fuels.

At a cement plant in the Middle East the kiln and calciner were typically run using 80% NG, supplemented by 20% Heavy Fuel Oil (HFO). However, as HFO is significantly more expensive than NG, the plant wanted to eliminate any HFO firing. When this was attempted by installing gas burners in the same location in the calciner as its HFO burners, the plant experienced significantly detrimental effects, including high temperatures and CO emissions at the preheater exit and a reduction in feed rate to 200 t/h.

The plant could have continued their trial and error approach using different burner designs and suffer high fuel costs and low production. Instead, FCT Combustion was engaged to study their calciner, determine what was limiting the substitution of natural gas and deliver a cost-effective solution. This article discusses how FCT used CFD modelling of the calciner and installed new burners that enabled the calciner to operate on 100% natural gas, saving €500k to €600k per year, whilst increasing kiln feed rate by 15% and reducing specific fuel consumption by 4%.

Figure 1: 4 stage in line calciner.
Modelling the Calciner

When changing a calciner from firing HFO to NG it is not just a matter of installing new burners in the same location as the existing ones. There are many factors that need to be considered and understood including:

• The inherent differences between the fuels and how they disperse, mix and burn,
• The aerodynamics of the calciner vessel,
• The location of the meal entry point(s), and
• The resultant heat transfer to the meal and degree of calcination.

In order to investigate the above factors, FCT Combustion built a computational model of the calciner in ANSYS Fluent. Table 1 below summarizes the boundary conditions used in the model. Total firing rate is 85 MW.

<table>
<thead>
<tr>
<th>Boundary</th>
<th>Mass flow rate</th>
<th>Temperature</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tertiary air inlet</td>
<td>26.17 kg/s</td>
<td>850 °C</td>
<td>Air</td>
</tr>
<tr>
<td>Kiln inlet</td>
<td>16.8 kg/s</td>
<td>1050 °C</td>
<td>17.25% H₂O; 12.48% CO₂; 0.401% O₂; 0.2% CO</td>
</tr>
<tr>
<td>NG inlet</td>
<td>1.497 kg/s</td>
<td>15 °C</td>
<td>86.85% CH₄; 7.97% C₂H₆; 4.67% N₂; 0.5% CO₂; 0.01% O₂</td>
</tr>
<tr>
<td>Primary air for gas burner</td>
<td>2 kg/s</td>
<td>13 °C</td>
<td>Air</td>
</tr>
<tr>
<td>HFO inlet</td>
<td>0.3856 kg/s</td>
<td>100 °C</td>
<td>C₁₀H₃₀</td>
</tr>
<tr>
<td>Primary air for oil burner</td>
<td>0.0753 kg/s</td>
<td>12 °C</td>
<td>Air</td>
</tr>
<tr>
<td>Meal inlet</td>
<td>54.83 kg/s</td>
<td>780 °C</td>
<td>54.85% CaCO₃; 26.47% SiO₂; 8.71% CaO</td>
</tr>
</tbody>
</table>
Simulating the Existing Operation

To understand the performance of the existing calciner, three operating conditions were modelled: (a) 100% HFO; (b) 20%HFO:80%NG; (c) 100% NG. In its original configuration, the calciner performance was characterised as:

- 100% HFO: fuel burns out well without high levels of CO,
- 20%HFO:80%NG: some CO is generated limiting further increase in natural gas firing and
- 100% NG: not possible due to high CO levels.

Figure 2 shows the aerodynamics and the temperature in the calciner vessel for these scenarios. In all cases the dominance of the tertiary air is evident, generating flow recirculation in the calciner. However, the flow fields are quite different, and recirculation regions change sides as NG is introduced in the system. These changes in flow pattern, associated with the higher ignition temperature and lower heat transfer of NG, influence the flame position and the upward extent of the high temperature region, creating stratification and impacting on calcination.

![Figure 2: Aerodynamics and temperature for 100% HFO (left), 20%HFO:80%NG (middle), and 100%NG for existing burners (right).](image)

Modelling of the calcination showed that for 100% HFO firing the calcination is complete at approximately half the height of calciner vessel, while in the cases where gas is co-fired or used as the only fuel, part of meal particles reaches the top of the vessel with its full content of CaCO3, i.e., completely uncalcined.

When the fuel burnout was assessed, for 100% HFO, the burnout is 100% complete by 9m above the burners. However, when firing with 20%HFO:80%NG, the fuel burnout is not complete at the calciner exit and combustion continues on into the bottom stage cyclone, raising the calciner exit temperature and, therefore, also the preheater exit temperature. When firing 100% NG, at least 6% of the fuel leaves the main calciner vessel unburnt. Although fuel oxidation continues in the outlet duct, approximately 1.8% of the fuel enters the cyclone unburnt, causing the high CO emissions.
Finding a Solution with CFD

The computational predictions of the existing calciner and burners were consistent with the actual calciner performance issues seen on the plant. In particular they showed that there is a difference in the velocity and temperature fields between the various firing configurations, which also affects the calcination pattern.

In order to find a solution for the 100% NG case, FCT considered a wide range of new burner designs and locations for the calciner. The best solution identified was to install two new FCT burners in the exit of the Tertiary Air Duct (TAD) to preheat the tertiary air and, therefore, enhance the rate of reaction of the natural gas injected at the main burners. In this configuration, 87% of the total firing rate is provided by the existing four burners, while the two new FCT burners in the TAD burners provide the remaining 13% of the heat output. In this way the temperature of tertiary air is raised to accelerate the reaction rate of NG to be comparable with HFO rate so that calcination reaction is activated with sufficient heat and completed within meal particles average residence time. The effect of new burners in the TAD on the calciner temperature field is shown in Figure 3.

![Temperature field in the calciner after the addition of the new FCT burners in the TAD.](image)

The impact of new burners in the TAD on calcination was predicted to be comparable to the 100% oil case, without uncalcined particles reaching the top of the equipment.

The effect of different burner configurations on the fuel burn-out, as a percentage of total fuel consumption, is compared at various distances above the existing burners in Figure 4. The burnout performance on 100% NG with the new TAD burners is better than the existing 80%NG-20% HFO, approaching that of the 100% HFO case.
Figure 4: Fuel burnout comparison of the existing burners with the addition of the FCT burners in the TAD.

Results from Real Life Implementation

The CFD study predicted that adding two small gas burners in the TAD will produce a significant increase in performance. This was a practical and cost-effective solution that did not require altering the design/layout of the existing gas burners. Hence, two new burners from FCT Combustion were purchased. These burners were designed to fire about 10% of the total gas supply to the calciner. They were installed in opposing positions in the TAD, as shown in Figure 5.

Figure 5: Installation of the FCT burners in the TAD.
During the commissioning period, the kiln was initially operated on the original burners firing 100% NG, achieving a feed rate of only 200 t/h. Within seconds of turning on the additional FCT burners the preheater exit temperature dropped 16 °C even though there was increase in the total calciner firing rate, demonstrating that the new burners had improved the calciner performance by increasing the degree of calcination and absorbing more heat from fuel combustion.

In the days following the installation of the new FCT burners, the kiln feed rate was increased by 15%, to 230 t/h, whilst maintaining the preheater exit temperature at the level previously attained at 200 t/h, as shown in Figure 6. In addition, the specific fuel consumption dropped 4% and clinker quality was maintained.

![Figure 6: Calciner gas firing rate and kiln feed rate before and after FCT burner optimisation.](image)

**Conclusion**

Using CFD, FCT Combustion has successfully improved the operations of a cement kiln calciner, in particular decreased its fuel costs and increased its production. The computational model built by FCT enabled unique insight into the aerodynamics, combustion and calcination process in the calciner in the existing operation and to develop a cost-effective solution that delivered substantial benefits when implemented in real life.

The CFD model demonstrated that the key difference from firing different fuels in the calciner was the velocity and temperature fields between the various firing configurations, which affected the calcination pattern. A solution was identified of installing new FCT burners in the TAD, in order to accelerate combustion of natural gas and produce an even heat distribution in the calciner vessel. Only 10% of total gas supply was redirected to these new burners, which were simple to install. This illustrates that in a calciner, the burner location is often more important than the design of the burners themselves.

When the new FCT burners were installed in the TAD, the calciner was successfully able to operate on 100% NG. By eliminating the use of HFO, it is estimated savings of €500k to €600k per year were realised. Furthermore, the kiln feed rate was increased 15%, whilst maintaining the preheater exit temperature, the specific fuel consumption dropped 4% and the clinker quality was maintained.