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Suspension burning for tyre fuel optimisation in precalciner Kilns

This paper looks at how to optimise substitution rates of Tyre Derived Fuel (TDF) in precalciner kilns using suspension burner technology. Both preheater and precalciner kilns using TDF on the feed shelf face technical challenges, but there are measures that can be undertaken to solve these limitations and to achieve high TDF substitution rates while maintaining operational stability and observing environmental requirements.

Tyre Derived Fuel (TDF) has conventionally been a solution aimed at lowering operational costs, ensuring environmental compliance, and maintaining product quality. Facilities using mid-kiln firing for long kilns and feed shelf firing for preheater kilns have achieved TDF substitution rates of up to 30%. However, with the introduction of precalciner kilns, the maximum fuel substitution with whole or shredded tyres on the feed shelf is typically limited to less than 5%. Both preheater kilns and precalciner kilns have experienced sulphur build-up problems with tyres on the feed shelf. The development of suspension burner technology enables precalciner kilns to achieve substitution rates of up to 30%, while minimising sulphur build-up in the tower.

Challenges

Precalciner kilns have observed limited results with the use of feed shelf firing primarily due to excessive sulphur build-up in the riser. This can be attributed towards two main changes in the sulphur cycle:

- Oxygen level;
- Localised reduction.

Sulphur cycle

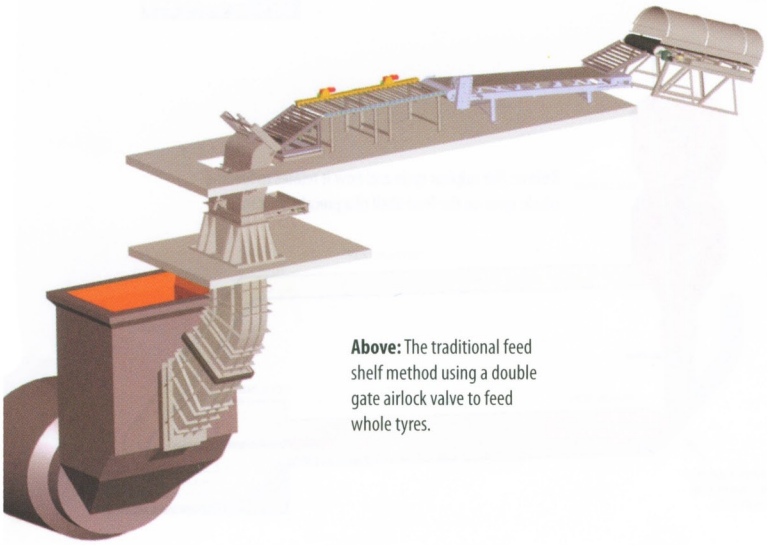
Sulphur introduced by the fuel combusts to form fuel-sulphur (SO_2 and SO_3). In the calcination zone, fuel sulphur begins to react with free lime at a temperature above 900°C to produce calcium sulphate ($CaSO_4$). The reaction reaches a maximum rate at 1050°C. This raw material sulphur ($CaSO_4$) travels downhill in the kiln feed to the burning zone. At the burning zone, 61%-64% of the sulphur volatilises while the rest of it will leave the kiln with the clinker. The concentration of sulphur can be four to ten times higher in the space between the calcining zone and burning zone than in the rest of the kiln. This volatilised sulphur travels back to the calcining zone and the cycle repeats itself:

$$S + O_2 \Rightarrow SO_2$$

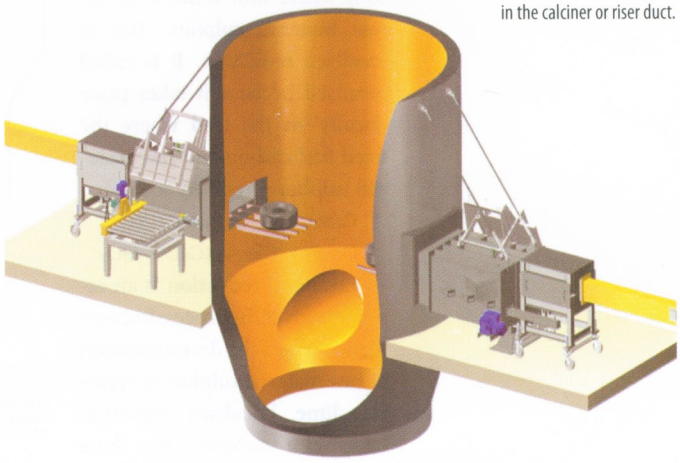
$$SO_2 + O_2 \Rightarrow SO_3$$

$$SO_2 + CaO \Rightarrow 3CaSO_4 + CaS \text{ (at below 1050°C)}$$

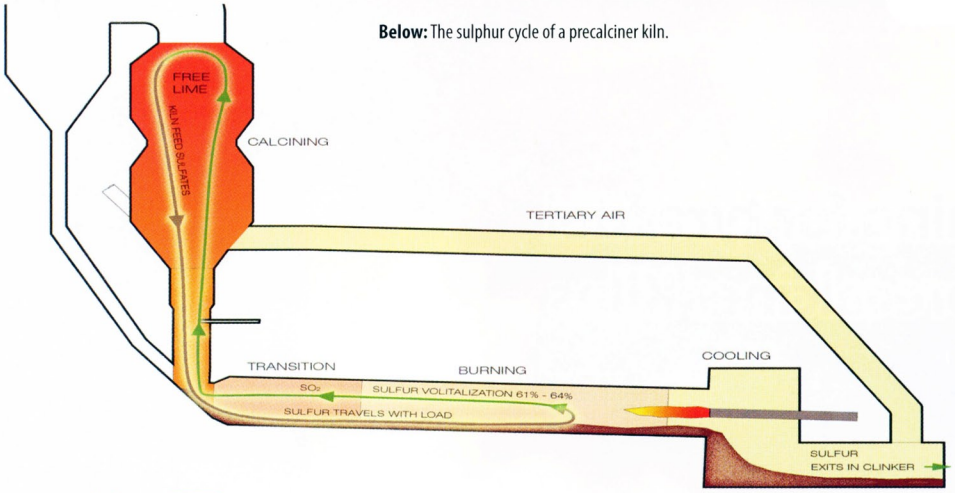
$$3CaSO_4 + CaS \Rightarrow SO_2 + CaO \text{ (at above 1050°C)}$$



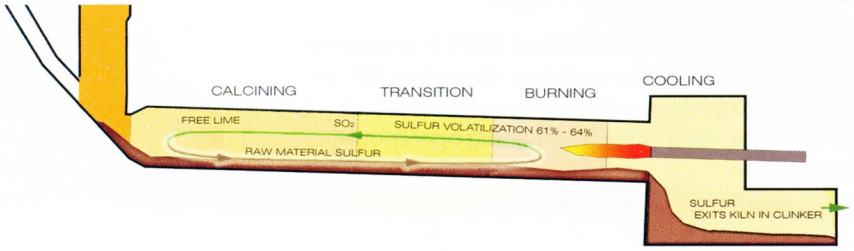
Above: The traditional feed shelf method using a double gate airlock valve to feed whole tyres.



Left: The Suspension Burner method suspends whole tyres in the calciner or riser duct.



Below: The sulphur cycle of a precalciner kiln.



Above: The sulphur cycle in a preheater kiln.

Sulphur buildup

When the volatilised sulphur is recovered as calcium sulphate the material condenses and a portion of the material adheres to the cyclones, riser duct and chutes. This continuous coagulation of calcium sulphate is the cause of build-up and tower plugs. Multiple air blasters are commonly used to control the level of this build-up, which can be seen on plants using alternative fuels all around the world.

Localised reduction

Reduction involves a decrease in oxygen and in this case it is a decrease in the raw material oxygen. The gas stream is being reduced by the volatiles in the fuel. When the volatiles deplete the gas stream of its oxygen, this leaves no oxygen for the slower burning fixed fuel carbon.

The fixed fuel carbon needs its oxygen for combustion from somewhere and finds it in the raw material sulphur. This is localised reduction. It is called localised because it takes place 'locally' in the feed where the fixed fuel carbon and raw material sulphur physically meet.

$CaS04 + 2C \Rightarrow CaS + 2C0_2$

$CaS04 + CaS \Rightarrow 4CaO + 4S$

Localised reduction is an essential part of the process because it encourages the decomposition of raw material sulphur to create free lime. Localised reduction becomes a problem when there is excess fixed fuel carbon introduced into the load above temperatures lOSO°C. This excess fixed fuel carbon produces additional sulphur which adds to the sulphur cycle and in turn creates unmanageable buildup in the tower. Hence, the balance of localised reduction and sulphur buildup are inter-related.

Process control parameters

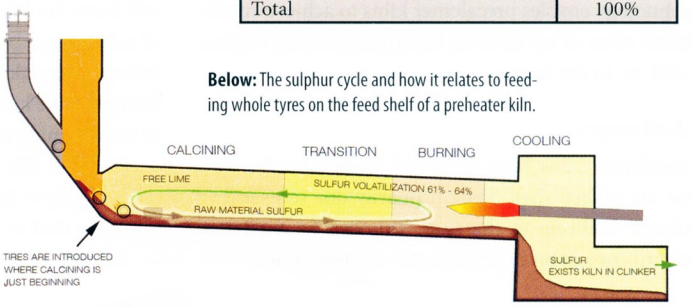
In order to deal with sulphur build-up and localised reduction on a daily basis the following measures are typically adopted:

- Air blasters are added throughout the tower to counteract the build-up;
- The kiln is operated under slightly oxidising conditions to ensure raw material sulphur (CaS04) decomposition to produce free lime.
- The amount of carbon added is carefully controlled as insufficient carbon results in contaminant CaS04 in the clinker and also results in a poor quality cement clinker: likewise too much carbon results in an excess CaS which reacts to compound the build-up in the sulphur cycle.

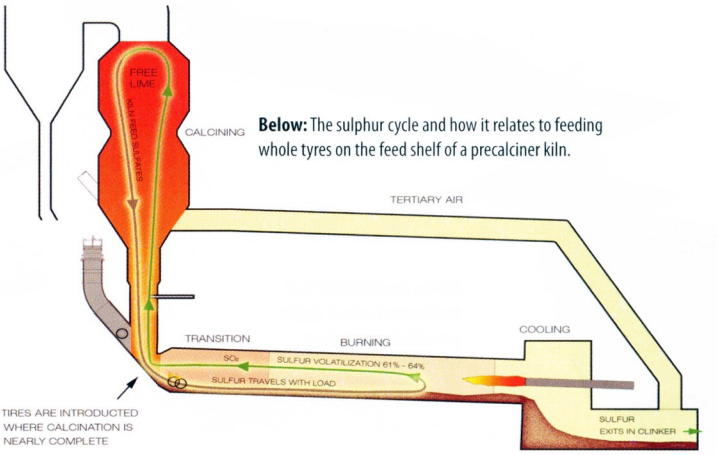
Preheater kilns vs. Precalciner kilns

Tyres are a great source of fuel for cement kilns because of their chemical composition:

Moisture	1%
Volatile matter	58%
Fixed carbon	24%
Ash	17%
Steel belting	13%
Other	4%
Total	100%



Below: The sulphur cycle and how it relates to feeding whole tyres on the feed shelf of a preheater kiln.



Below: The sulphur cycle and how it relates to feeding whole tyres on the feed shelf of a precalciner kiln.

However, to understand the limitations with using tyres on the feed shelf we must look at the reactions with volatiles, fixed carbons and steel belting.

Volatiles

Volatiles in the fuel are the first components to combust. This is because at about 300°C the volatiles in the tyre quickly combine with oxygen and ignite. This reaction depletes the small percentage of excess oxygen in the flue gases, thereby creating reducing conditions in the back end of the kiln. The remaining volatiles form carbon monoxide in the gas stream.

Fixed carbon

Fixed carbon is the solid combustible residue that remains after a tyre particle is heated and the volatile matter is expelled. Typically when a tyre is introduced onto the feed shelf of the kiln by a double gate airlock valve, it will be positioned in direct contact with the feed. Because of the depletion of oxygen by the volatiles, the fixed carbon will begin to react with the raw material sulphur to obtain its oxygen for combustion. The introduction of locally concentrated amounts of fixed carbon (tyres) to the feed shelf adds too much fuel carbon to the load, causing localised reducing conditions and consequently the problem of excess sulphur being added to the sulphur cycle.

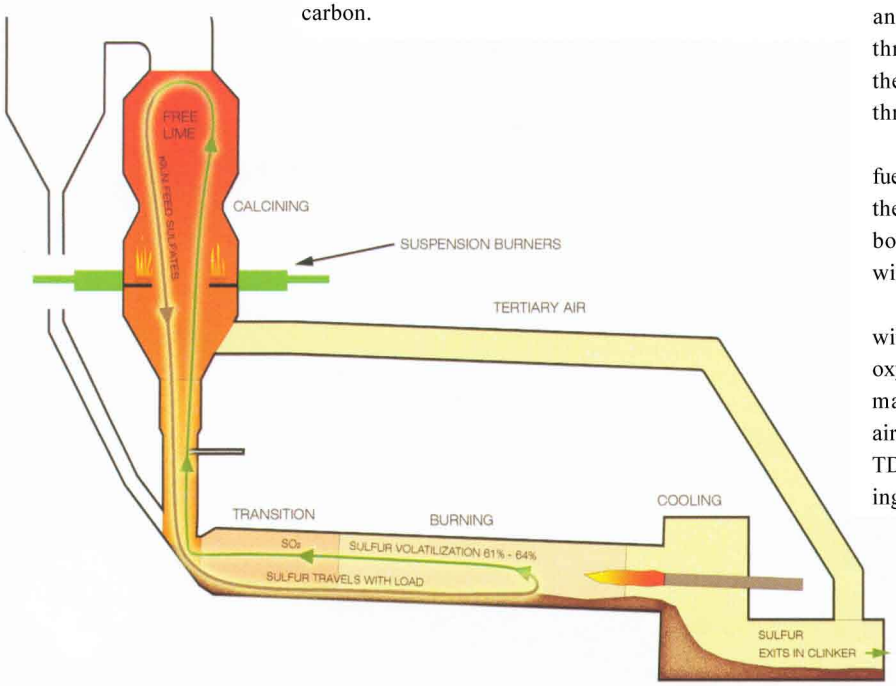
Steel belting in the tires

The steel belting is oxidised from iron metal (Fe) to iron oxide (Fe203). Like the fixed carbon, the iron also has the potential to cause reducing conditions.

Excess fixed carbon

Localised reducing conditions are not limited to TDF. The issue of build-up has been observed with the addition of any fuel with high fixed carbon content (for example coal ash). Therefore, the cause of localised reducing conditions is the addition of excess fixed carbon.

Below: The sulphur cycle in a precalciner kiln with suspension burning.



The use of TDF causes a sulphur issue with both preheater and precalciner kilns. Therefore, the upper limit of success with TDF on the feed shelf is decided by changes in the sulphur cycle.

Feed shelf	Preheater	Precalciner
Kiln feed temperature	850°C	1050°C
Flue gas temperature	1100°C	1150°C
Kiln combustion air	100%	40%
Level of calcination	25%	90%

There are two process differences that contribute to the higher success rate of TDF on the feed shelf of a preheater when compared to a precalciner: temperatures and oxygen levels.

Temperature

To understand why sulphur issues can be handled better in a preheater kiln when burning tyres we must first recognise where in the sulphur cycle tyres are being introduced and the temperature at this point.

As shown in the sulphur cycle figure for preheater kilns, the sulphur cycle is almost entirely within the kiln. Of course there is build up in the riser as well, but this is to a more manageable level when compared to precalciners and is controlled with the addition of air blasters.

Unlike the preheater kiln, the sulphur cycle in a precalciner extends much higher up in the tower and into the calciner. In the calcination zone we find that fuel sulphur begins to react with free lime at 900°C. If TDF on the feed shelf is increased, the amount of sulphur formed by localised reduction is greatly increased thereby causing the sulphur build up to reach an unmanageable level. Excessive build-up is found all along the riser. This will eventually lead to tower plugs.

Oxygen levels

Due to the inherent difference between preheaters and precalciners, 100% of the combustion air passes through the kiln in a preheater, while only 40% of the air going through the precalciner system passes through the kiln.

In a preheater kiln system, when tyres are added as fuel to the feed shelf it can directly substitute the fuel of the main burner because 100% of the oxygen to burn both fuels is introduced into the front of the kiln along with the primary fuel.

In precalciners there is not a direct substitution with front end burner fuel because only 40% of the oxygen is introduced into the kiln along with the primary fuel. This leaves only the small amount of excess air left for TDF combustion. When the combustion of TDF consumes the oxygen in the excess air the reducing conditions will increase the sulphur volatilisation.

You may ask 'Well then why don't we just add more air to the front of the kiln?' However, large amounts of excess air cannot be added to the front of a precalciner kiln without cooling the primary flame and affecting clinkering.

OK, so what's the solution?

Recognising the problems with the use of TDF on the feed shelf of precalciner kilns, Cadence Environmental Energy, Inc. and Ash Grove Cement developed the concept of suspension burning of whole tyres in the riser or calciner. They were issued a US patent in October 1998. The sulphur cycle and suspension burning in a precalciner kiln is pictured on page 46.

Benefits of suspension burning:

• Suspension burning maximises the combustion of each tyre by utilising the oxygen of the TA duct and directly substituting calciner fuel;

• Suspension burning substantially reduces the localised reducing conditions in the kiln;

- Since the tyres are suspended there is minimum direct contact between the fixed fuel carbon and the raw material sulphur (CaS04). The fixed fuel carbon acquires its oxygen from the gas stream instead of the raw material sulphur, thereby minimising the addition of sulphur to the sulphur cycle;
- At this injection point the temperature is much lower than in the feed shelf. In order for the CaS04 to react with the CaS to produce free lime and sulphur dioxide we need temperatures of above 1050°C. Therefore the CaS04 and CaS react at a very low rate to produce negligible extra sulphur thereby having minimal impacts on sulphur build-up.

$3CaS04 + CaS \Rightarrow S02 + CaO$ (at above lOSO°C)

Suspension burning minimises the excess air required to maintain proper oxygen levels in the back end of the kiln;

- Suspension burners do not disrupt operational stability in the feed shelf and the oxygen level in the kiln can be controlled to a greater extent.

Another potential advantage of suspension burning is lower NOx emissions. On average tyres contain twice as much volatile matter compared to coal. Therefore, as the tyre combusts on a suspension burner, there is more instantaneous CO formation from the volatiles. This CO helps to destroy NOx.

$2\ CO + 2NO \Rightarrow 2CO_2 + N_2$

New Equipment

AFS Technology of Tipp City, Ohio, has designed and fabricated suspension burners and fully-automated tyre handling systems to utilise this concept. The suspension burner consists of a weigh feed conveyor, a double gate airlock chamber, a ram to push the tyre into the calciner, a nozzle to connect the suspension burner assembly to the calciner and a four-tine high temperature alloy suspension fork inside the calciner.

While on the suspension fork the volatile matter gasifies and the fixed carbon and steel belting in the tyre begin to combust. The residual steel belting from the tyre is pushed off the end of the suspension fork and falls to the feed shelf. In the kiln the steel is completely oxidised and reacts to become part of the clinker.

Operating experience

FLS Calciner - Above the Tertiary Air Duct

The first commercial test of this concept began in 2002 at a four-stage FLS precalciner kiln. The suspension burner was installed above the tertiary air duct in the calciner in late 2002. Based upon the success of the initial suspension burner test the plant installed a semi-automatic (manually loaded) tyre handling and suspension burner system in late 2003. In 2006 the plant tested feed shelf firing, but stopped due to excessive CO and low replacement rates. In 2007 the plant installed a second suspension burner which produced good results similar to that of the first suspension burner.

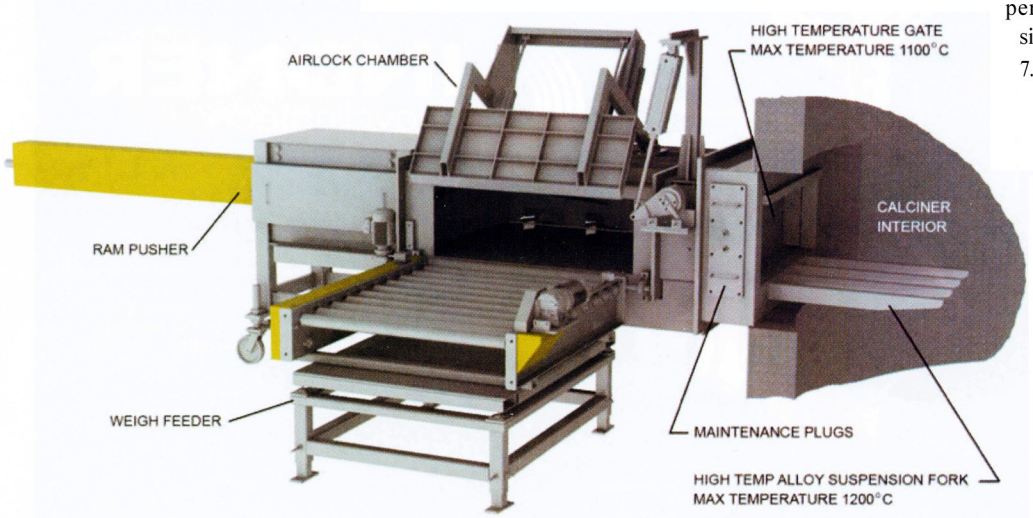
The following results were observed by using a suspension burner:

1. Average fuel replacement was approximately 10%, or 1*t/hour* of tyre fuel per burner.
2. Clinker production decreased by *0.5t/hour* for small tyres to *2t/hour* for truck tyres.
3. Oxygen in the back end of the kiln decreased slightly.
4. Carbon monoxide in the back end of the kiln increased.
5. Tower plugging went from none to two per year.
6. Tyre burn time ranged from 25 seconds for small (7kg) tyres to 360 seconds for 80kg for truck tyres. This suggests a feed rate of ~15 *kg/*min or 1*t/hour* per suspension burner, regardless of the tyre size.
7. The suspension fork tines were in use for 2 years before being replaced.

The decrease in oxygen and increase in carbon monoxide at the kiln inlet indicate that some of the tyre combustion was still occurring in the kiln at these feed rates. AFS is extending the length of the fork to increase the suspension time and therefore expecting to reduce these conditions.

Polysius Down-Draft Calciner

Another commercial test of suspension burning occurred in late 2004 on a five-stage downdraft calciner kiln. The testing



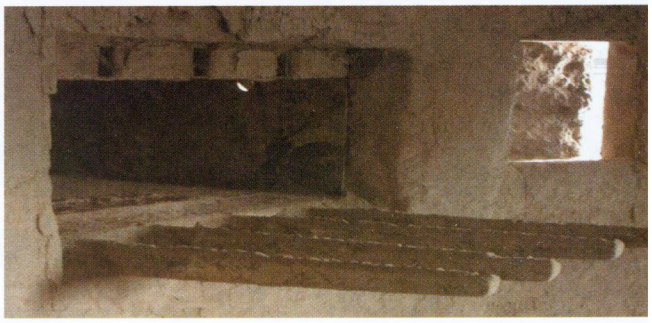
Below: The AFS Suspension Burner, for maximised precalciner tyre feed rates.

was very successful for the first five days, but after this time a large pressure drop in the riser was noted and the kiln stopped. A large ball of tyre wire was found in the riser. It was determined that because of the high gas velocities, caused by the small orifice at the base of the riser, the tyre wire could not fall into the kiln and had accumulated into a ball.

In a recent proposal for a similar design of a downdraft calciner, AFS has proposed that the suspension burner be placed below this orifice.

KHD Calciner - Below the Tertiary Air Duct

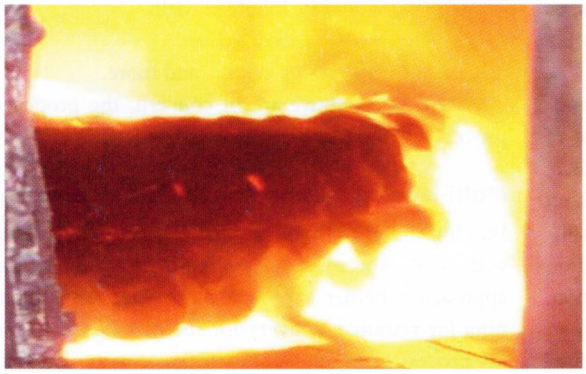
Another commercial test of suspension burning is currently underway. The goal of this test is fuel replacement and NOx reduction. To achieve this, the suspension burner is placed in the riser duct below the tertiary air. The first attempt resulted in overheating of the suspension fork due to the fork being placed directly above the calciner fuel inlet. The suspension burner was then moved further up the riser to a point approximately 5 metres below the tertiary air duct. This resulted in three days of excellent results achieving 1.5 tons per hour of tyre fuel with the one burner. The rate was then increased to 1.9 tons per hour for a period of three hours. After this period the kiln experienced a loss of feed to the riser, resulting in a series of temperature excursions above 1260°C. This again caused damage to the suspension fork and the testing was stopped.



Above: Suspension forks inside the calciner, during a plant maintenance interval.

Because of the good results prior to the temperature excursions, efforts are being made to continue testing. To avoid any further damage to the fork from unexpectedly high temperatures, AFS is now including controls to monitor temperatures and automatically retract the forks in the event of excessive temperatures.

1. Localised reducing conditions increase sulphur recycling in kilns.
2. Feeding tyres on the feed shelf of precalciner kilns is limited, compared to preheater kilns, due to the lower oxygen levels and the higher load temperature at the back end of the kiln.
3. Suspension burners can directly substitute for calciner fuel.
4. Suspension firing minimises localised reducing conditions.



Left: Tyre burning on suspension forks.