Kiln rings, balls and snowmen

To eliminate and prevent kiln rings, balls and snowmen cement plant operators need a fundamental understanding of their root causes as well as practical experience of the possible solutions.

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Due to characteristics of the cement production process, cement plant operators face several challenges when producing high-quality cement. These include:

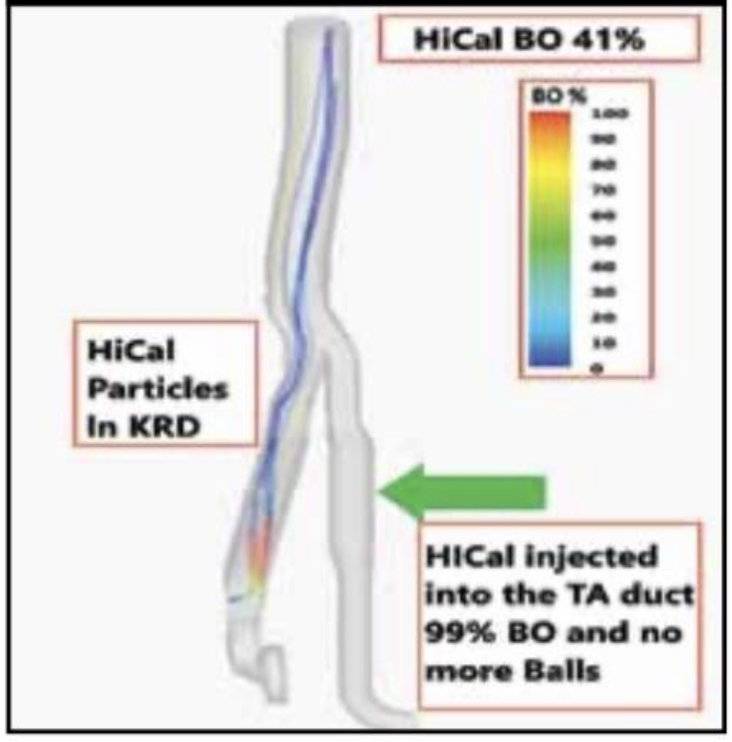
- **kiln rings** – These occur in many kilns around the world. They are mostly sulpho-spurrite, but can also be spurrite or, less frequently, the more dreaded sinter rings.
- **kiln balls** – These form less frequently but are a bane of production as they can grow sufficiently large to lodge under the kiln burner.
- **snowmen** – These are seen more often with the birth of the more efficient IKN-type coolers. They can form in the kiln as 'dragon's teeth' or 'rhino horns', but are mostly found in the cooler, reducing its performance.

To prevent or eliminate these build-ups, a fundamental understanding of their root causes is required. Several tools are available to support kiln operators in solving this issue:

- a combinability temperature (CT) assessment that can be readily used by a plant with a simple laboratory test
- ability to predict 1338˚C Lea Parker (LP) liquid as well at the actual CT
- knowledge of SO_3 cycles and their drivers
- strong process and clinker chemistry knowledge and plant experience, plus TRIE SMART FLOW as needed.

Figure 1: alumina-silica ratio and impact on liquid, kiln balls and coating

Figure 2: HiCal burn-out in the calciner riser



Kiln balls

Figure 1 shows the classic diagram of the silica ratio (SR) versus alumina ratio (AR) used over the years. In the figure, the optimum SR is 2.5 while the optimum AR is 1.5. Combined with good plant data, it shows the typical kiln ball formation region in the top-left quadrant with an SR and AR of say, 1.7 and 2, respectively. Clinker chemistry in this quadrant should be avoided to prevent kiln ball formation. However, this is far from correct.

Figure 1 also shows two example cases:

- Case 1 (red smiley face): severe ball formation on a regular basis
- Case 2 (green smiley face): intermittent ball formation.

Figure 3: kiln ball at the nose ring

Case 1 – severe, regular ball formation

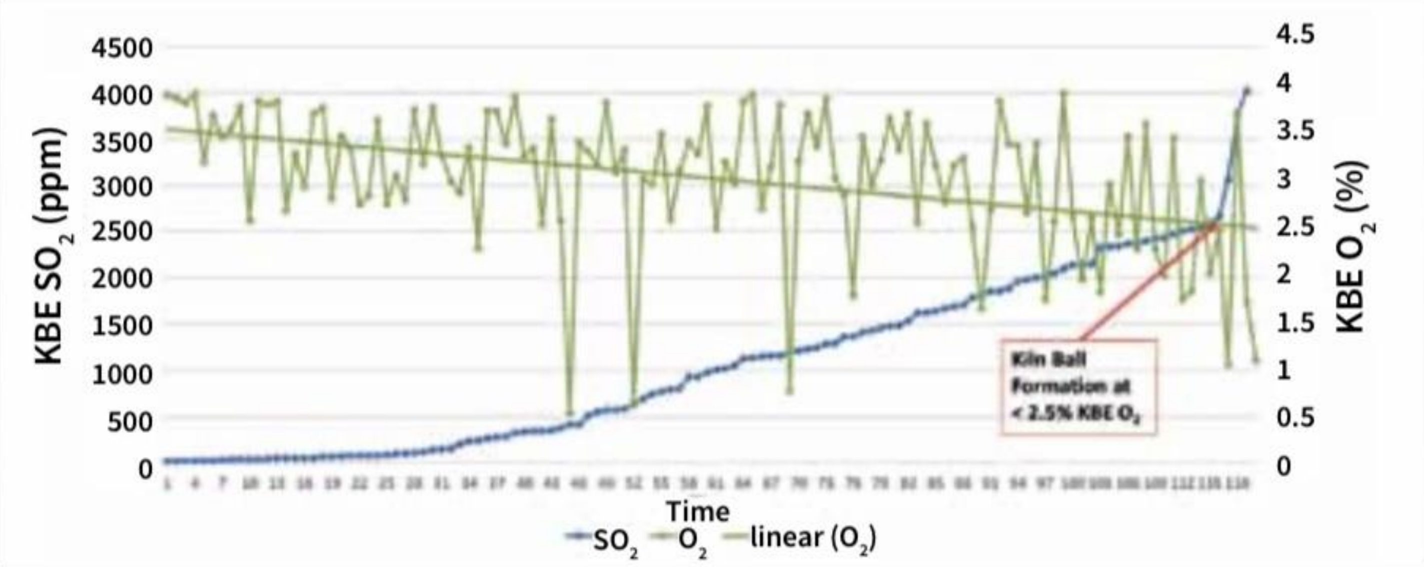
The cement plant in Case 1 operated with an excess alkali-SO_3 ratio in the clinker and hot meal. Therefore, excess SO_3 cycles were ruled out as a cause of ball formation. However, as part of an AFR optimisation investigation it was found that the HiCal, produced by Regain from spent pot liners and injected into the riser leg of the KHD calciner, was only burning out to 41 per cent (see Figure 2). The simulation for injecting this into the tertiary air riser showed a 99 per cent burn-out and when carried out in the plant, it eliminated kiln balls for six months.

Nevertheless, the issue returned with a vengeance (see Figure 3). A detailed investigation uncovered that the control of the Fe_2O_3 in the kiln feed had become erratic and when clinker Fe_2O_3 surpassed five per cent, kiln balls were formed.

Case 2 – intermittent ball formation

Case 2 arose following the previous investigation and while the issue had been around for several years, many investigations had failed to eliminate the

Figure 4: impact of KBE O_2 on SO_3 cycles in calciner with high TSR



kiln balls. A check on the chemistry and Fe_2O_3 proved fruitless. However, the plant was running with a high calciner thermal substitution rate (TSR) and the Cl and SO_3 in the hot meal were variable. Tests for hot meal carbon (HMC) showed it to be between 0.1-0.5 per cent, which at the higher end was similar to the poor HiCal burn-out.

Fortunately, the plant had an online kiln back-end (KBE) SO_2 monitor that worked well and presented typical KBE SO_2 vs O_2, shown in Figure 4. Kiln balls were eliminated by running at a KBE O_2 of 2.5 per cent.

Kiln rings

There are three types of kiln rings: sulpho-spurrite, spurrite and sinter rings – their locations are shown in Figure 5.

Sulpho-spurrite rings

The most common type of kiln ring, the sulpho-spurrite ($2C2S.CaSO_4$) ring is very hard and formed at around 10-15D from the kiln discharge end. Their formation is either driven by the burner (Case 3) or the calciner (Case 4). However, sulpho-spurrite rings are the easiest to understand and control.

Case 3 – burner-driven sulpho-spurrite kiln rings

Burner-driven sulpho-spurrite rings are due to excess SO_3 cycles as a result of hard burning or reducing conditions. However, this way of ring formation requires a significant excess of SO_3 over alkalis in the clinker, with clinker molar ratio (MR) >1.5.

Figure 6 shows a graph of CT versus +90µm raw meal (RM) acid insoluble residue (AIR) for a calciner plant with 100 per cent petcoke, having a clinker SO_3 of two per cent with a Na_2O equivalent of 0.4, ie a MR of 3.9.

The plant normally runs at a CT of 1460˚C with a 97 LSF and two per cent +90µm AIR and there are no ring issues. However, once the LSF gets out of control, due to poor blending, and reaches >101, the operator sees high free lime. They then take the CT >1500˚C and the excess SO_3 in the form of $CaSO_4$ breaks down at 1420˚C and langbeinite ($2K2SO_4.CaSO_4$) at 1520˚C. The plant sees a rapid build-up of rings at 14D.

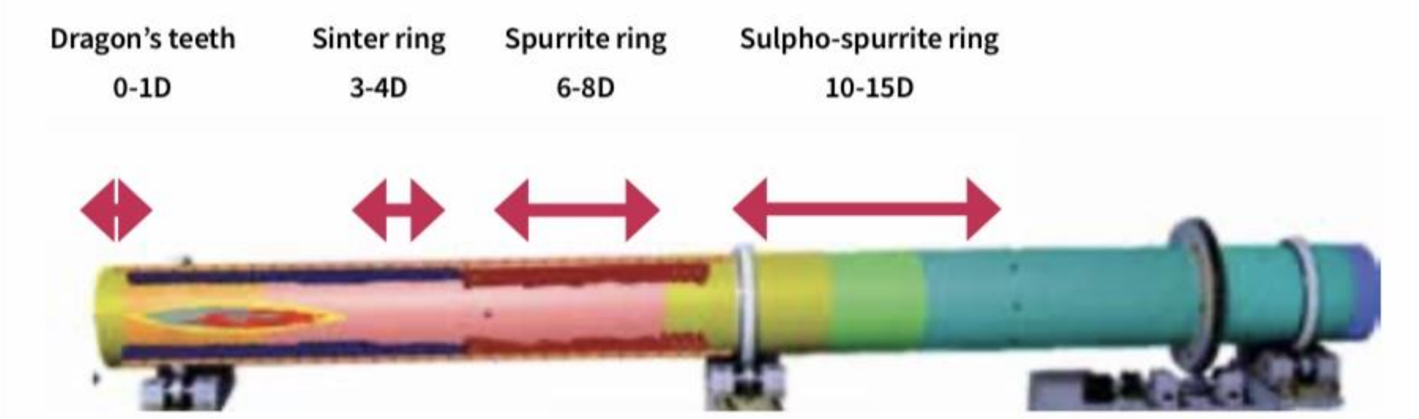
To be caused by reducing conditions, burner-driven sulpho-spurrite rings are due to flame impingement or too low KBE O_2. The best test for reduction in the absence of blatant brown core is the soluble and water-soluble alkali test, and comparing the insoluble levels to what they should be based on the actual clinker chemistry. This test can also be used to predict the maximum level of orthorhombic C_3A and compared to XRD/microscopy for clinker quality control.

Case 4 – calciner-driven sulpho-spurrite kiln rings

Calciner-driven sulpho-spurrite rings are due to the inadequate burn-out of fuel in the calciner and having unburnt carbon in the hot meal (normally >0.2 per cent) which, when combined with the KBE O_2, allows unburnt carbon in the after-calcination zone to volatilise excess SO_3 in the form of $CaSO_4$ by reduction. It can also arise when the SO_3, alkalis and Cl in the hot meal are all at a level where the excess SO_3 = SO_3-(Na_2Oeq-0.9Cl) x 1.29 is >1.5 per cent.

A useful procedure to establish is the level of SO_3 retention in the process from a daily balance. Table 1 shows the results from a plant that is prone to intermittent sulpho-spurrite rings, driven primary by a periodic (weekly) shortfall in alkalis in the raw material that drives the excess SO_3 in the hot meal up to three per cent. Therefore, the retention of process SO_3 reaches 20 per cent, leading to build-ups

Figure 5: kiln rings and their locations



Dragon's teeth are really snowmen formed at the kiln discharge. Sinter rings form in the middle of the burning zone while spurrite rings form just after the burning zone. Sulpho-spurrite rings form in the back third of the kiln.

Figure 6: combinability temperature vs +90µm RM acid insoluble residue and clinker LSF

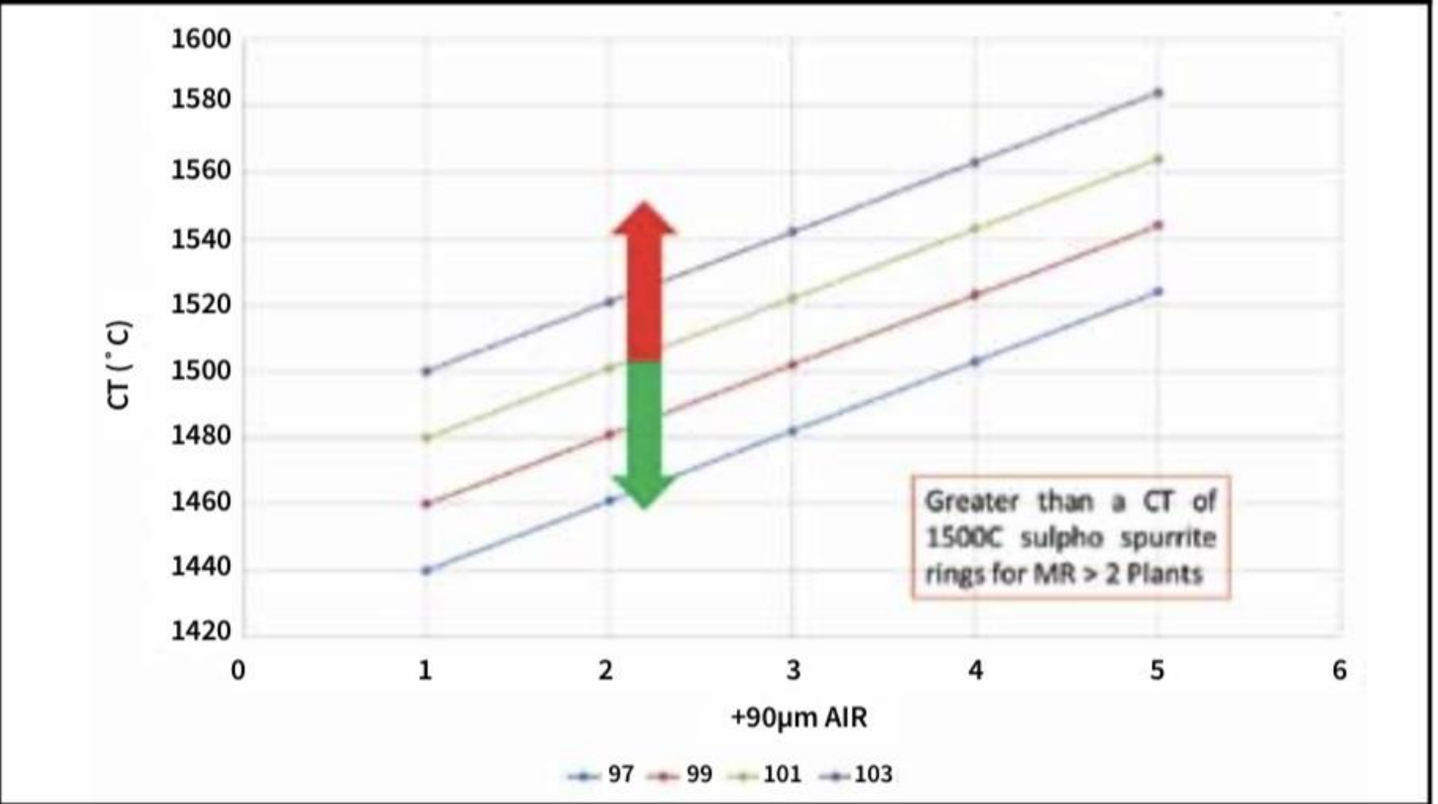


Figure 7: XRD of kiln ring at 8D (red line is spurrite)

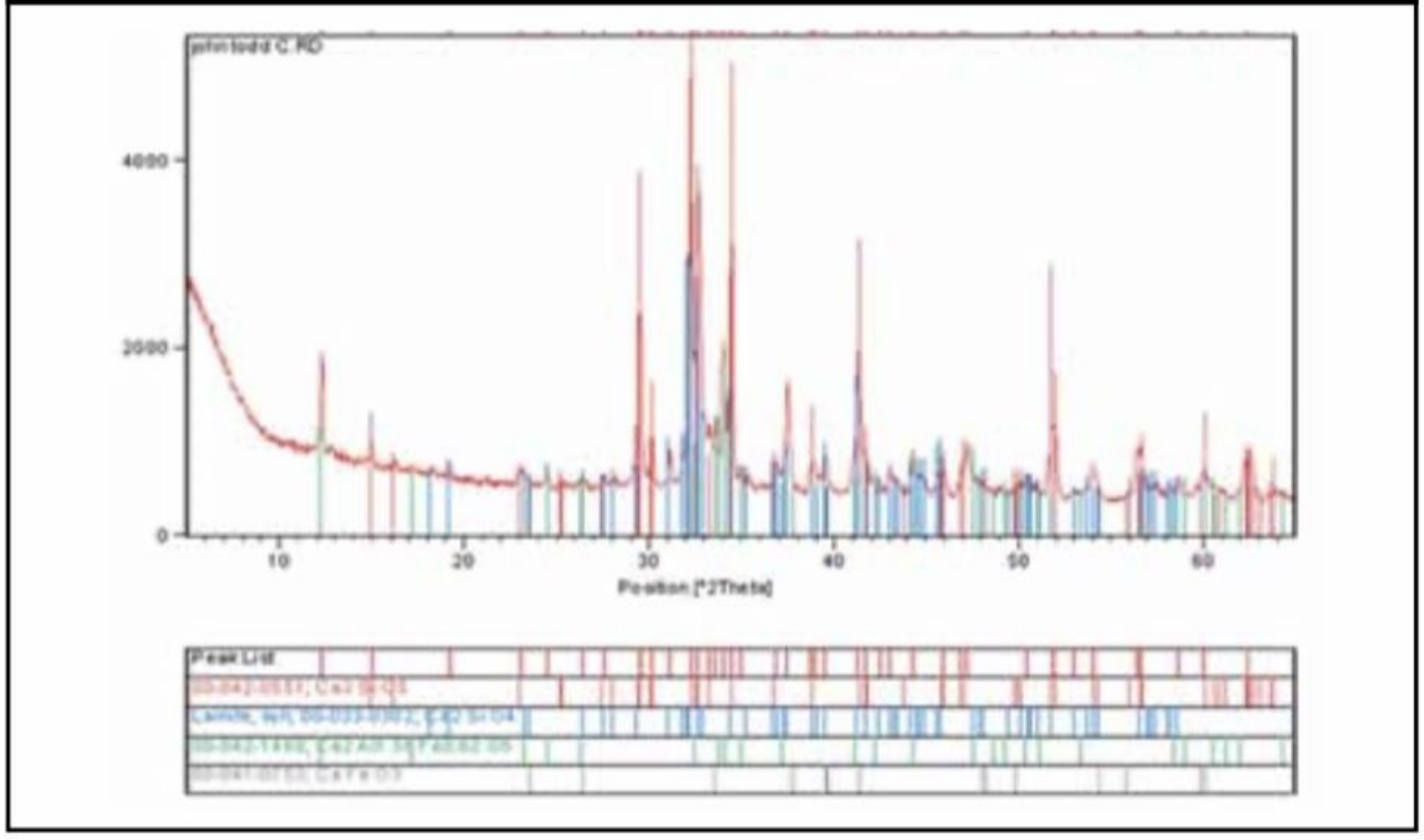


Table 1: SO_3-alkali balance

	SO_3	Na_2O eq	MR	Cl
Input	1.1	0.32	2.9	0.026
Output	0.9	0.31	2.7	0.014
Difference	0.2	0.01	0.2	0.013
$CaSO_4$ build-up 3.7m³/day				

and sulpho-spurrite rings.

If a plant uses X-ray diffraction for hot meal analysis, monitoring for chloroellestadite ($2C2S.CaSO_4.CaCl_2$) will provide an early warning of potential sulpho-spurrite ring formation.

Therefore, to avoid sulpho-spurrite rings:

- keep a CT of <1500˚C
- avoid reduction in the burning zone
- aim for the HMC of ≤0.1 per cent – via Leco for carbon, following the special sampling procedure available from TRIE Engenharia
- target an excess SO_3 in the hot meal of <1 per cent by maintaining volatilisation factor (VF) SO_3 at <2.

Spurrite rings

Spurrite rings occur less frequently than sulpho-spurrite rings and as $2C2S.CaCO_3$, contain $CaCO_3$ instead of $CaSO_4$.

Case 5

A cement plant had experienced an elusive intermittent kiln ring for several years. While it was thought to be sulpho-spurrite, XRD analysis of a ring sample showed that this was a spurrite ring (see Figure 7).

Therefore, the question arose as to why it was forming and how this could be prevented in the future. The cause was traced back to the quarry and the RM 70 mesh/210μm, which was five per cent and rich in calcite. The calcite was not releasing its CO_2 as fast as normal limestone and existed at the same location as C_2S formation, resulting in the formation of spurrite. The solution to the issue was to selectively quarry and avoid the regions with high calcite.

Sinter rings

Sinter rings are the least understood and literature on them remains vague. The most comprehensive statement comes from Dr Michael Clark: "Once the temperature is high enough for significant flux formation then coating begins to form on the refractory lining, but any local cooling can cause the flux to freeze and the coating to grow into a ring at the point. At the beginning of the burning zone where the flux is first forming the refractory is successively cooled as the kiln rotates and the lining is exposed to the hot kiln atmosphere and then cooled as it turns into the cooler charge. The flux adhering to the lining softens as it is expected to in the kiln atmosphere and then stiffens as it is cooled by turning into the charge. The weight of the charge causes solid particles to adhere to the stiffening flux layer and a ring can rapidly grow."

While this is comprehensive it provides little support to a cement plant's plans for preventative action, apart from telling it that such rings occur when the melt is there. However, Case 6 provides some guidance for plants experiencing this issue.

Case 6

A cement company was producing oilwell cement in one plant (C6a), and OPC and oilwell in a second plant (C6b).

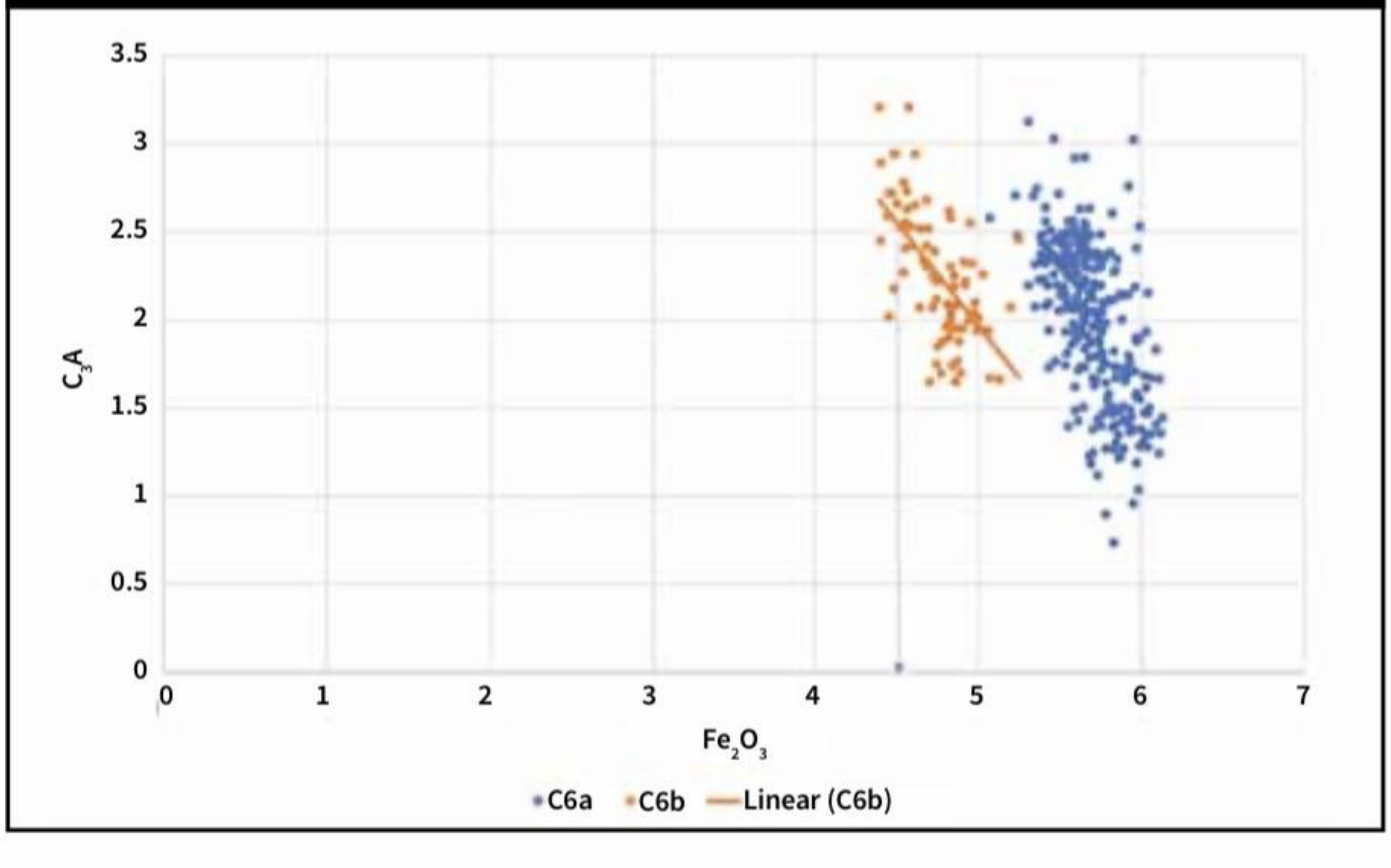
Plant C6a saw ring formation since it started producing oilwell cement. Plant C6b initially suffered with sulpho-spurrite rings when producing OPC, but these were eliminated with a kiln burner change and operation at a higher KBE O_2. However, when it started producing oilwell cement, the kiln rings reappeared – this time much nearer the nose ring at 4D.

XRD analysis of the rings showed that they were neither forms of spurrite, and chemical analysis showed they were similar to the clinker. Therefore, they had to be sinter rings.

Detailed root cause analysis on C6b showed that ring formation appears to occur when the C_3A is <2.5. It was also being driven by reducing conditions due to CO and too coarse pulverised fuel (PF) residue.

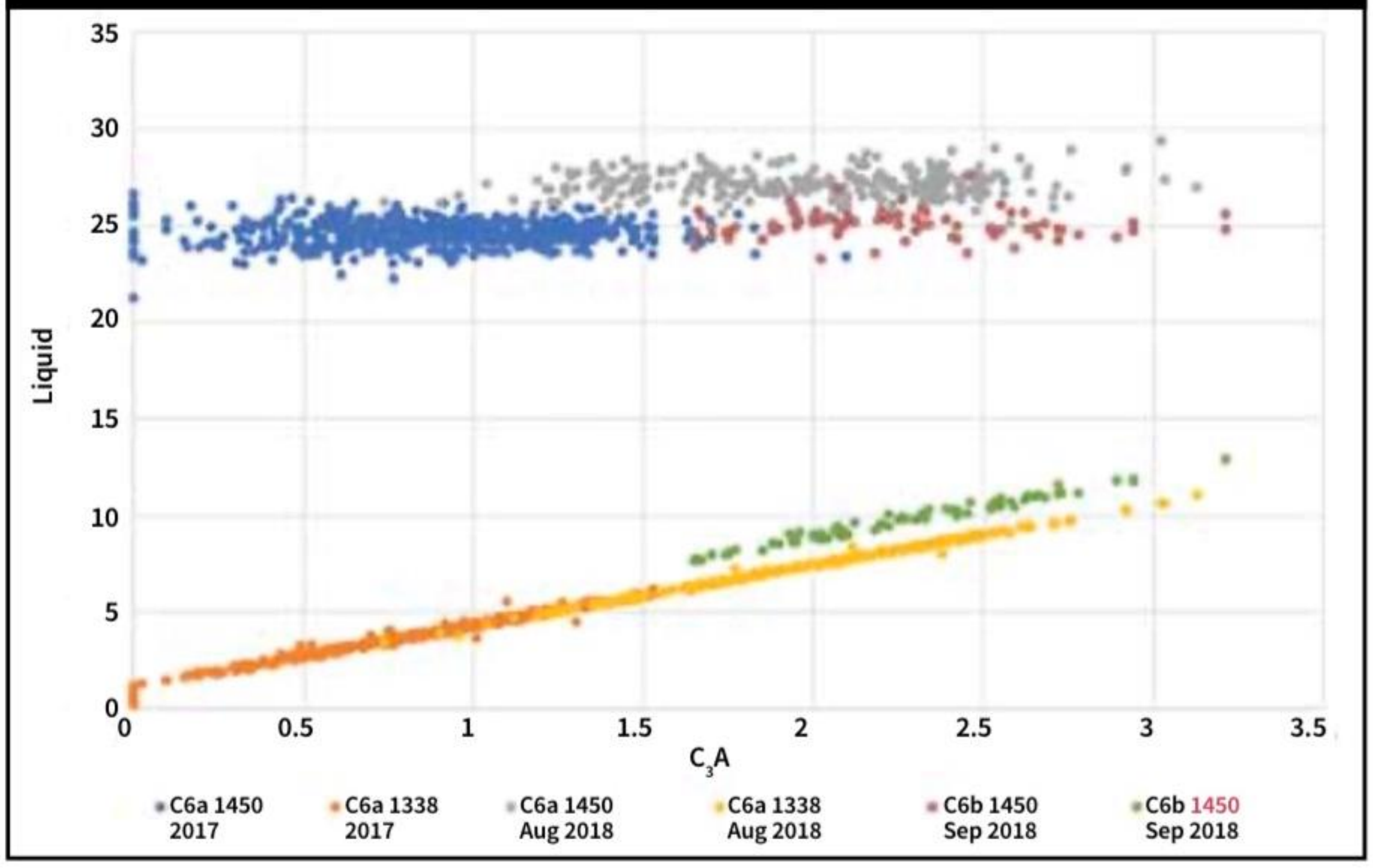
It is likely that the C_3A effect is tied

Figure 8: C_3A vs Fe_2O_3 of plants C6a and C6b



to the Fe_2O_3 content and therefore, C_4AF levels and the amount of viscous Fe_2O_3 liquid. This is shown on Figures 8 and 9, where the C_3A level is linked to the Fe_2O_3 level. A Fe_2O_3 level of >4.5 per cent is not recommended. In addition, there must be at least 10 per cent 1338˚C liquid and a maximum gap between 1450˚C and 1338˚C liquid of 15 per cent. These requirements were met at the C6b plant, but the C6A unit had customers who liked extremely-low C_3A contents. Therefore, progress on the elimination of sinter rings has been relatively slow. The statement below by Dr Clark begins to relate to both kiln balls and sinter rings: "Mixes or clinkers with a wide 'clinkering range' create less operational problems such as ball or ring formation, than those with a narrow clinkering range. High Fe_2O_3 mixes tend to have a narrower clinkering range. With a narrow clinkering range any fluctuations in temperature can cause ball or ring formation to occur and fluctuations in temperature are inevitable with an industrial cement kiln."

Figure 9: C6a and C6b liquid vs C_3A



Snowmen

While snowmen have been around since the start of the use of grate coolers, they really became prominent with the introduction of the more efficient IKN-type cooler.

Snowmen are formed from refractory or kiln flush material dropping onto the fixed grate, sticking to it and then growing like a stalagmite with sticky alite dust generated in the cooler when the clinker is dusty and friable. They have the same growth mechanism as rhino horns (see Figure 10) and dragon's teeth.

The normal wisdom is to push the kiln burner further in to reduce the dusty clinker and result in a longer cooling zone with colder or less sticky clinker in the cooler. While this works sometimes, it does not provide a solution in most cases. Often the plant has to resort to multiple blasters in the cooler and even one embedded at an angle – Lafarge burner – on top of the burner.

Figure 10: rhino horn in kiln burner

However, a more fundamentally-based solution is available. Starting with a rhino horn as shown in the side view from the burner in Figure 10.

Case 7

The tendency to form snowmen is related to the dustiness of the clinker and the amount of liquid associated with the dust. Dusty clinker is caused by:

1. excess SO_3 over alkalis
2. reducing conditions
3. high combinability temperature.

Excess SO_3 over alkalis means the excess SO_3 goes into the LP liquid and reduces its viscosity. The same applies with reducing conditions. An increase in CT by 100˚C reduces the viscosity by 70 per cent and therefore, produces a dustier clinker.

The rhino horn in Figure 10 was caused by excess SO_3 over alkalis and reducing conditions. It was eliminated by burner modifications after CFD.

Figure 11 shows how, due to a combination of lower burner momentum and cooler/kiln hood geometry, there is no secondary air (SA) going under the burner, producing reducing conditions. Increasing the burner momentum from 6 to 11N/MW entrained more SA under the burner and eliminated reducing conditions and therefore, the rhino horn.

Case 8

When a clinker with a high CT (>1500˚C) is combined with an excess of SO_3 over alkalis, dusty clinker occurs with a friable outer layer of alite that retains some liquid going into the cooler. Table 2 shows a CT of 1612˚C for a plant with a high +90u acid insoluble residue and a high clinker MR due to petcoke firing with substantial snowmen issues after conversion from a conventional grate cooler to an IKN-type cooler. The clinker chemistry on the right shows the same plant with less petcoke and selective quarrying to reduce the amount of quartz and finer grinding, which has resulted in a decrease in the

Figure 11: kiln hood-kiln-burner aerodynamics

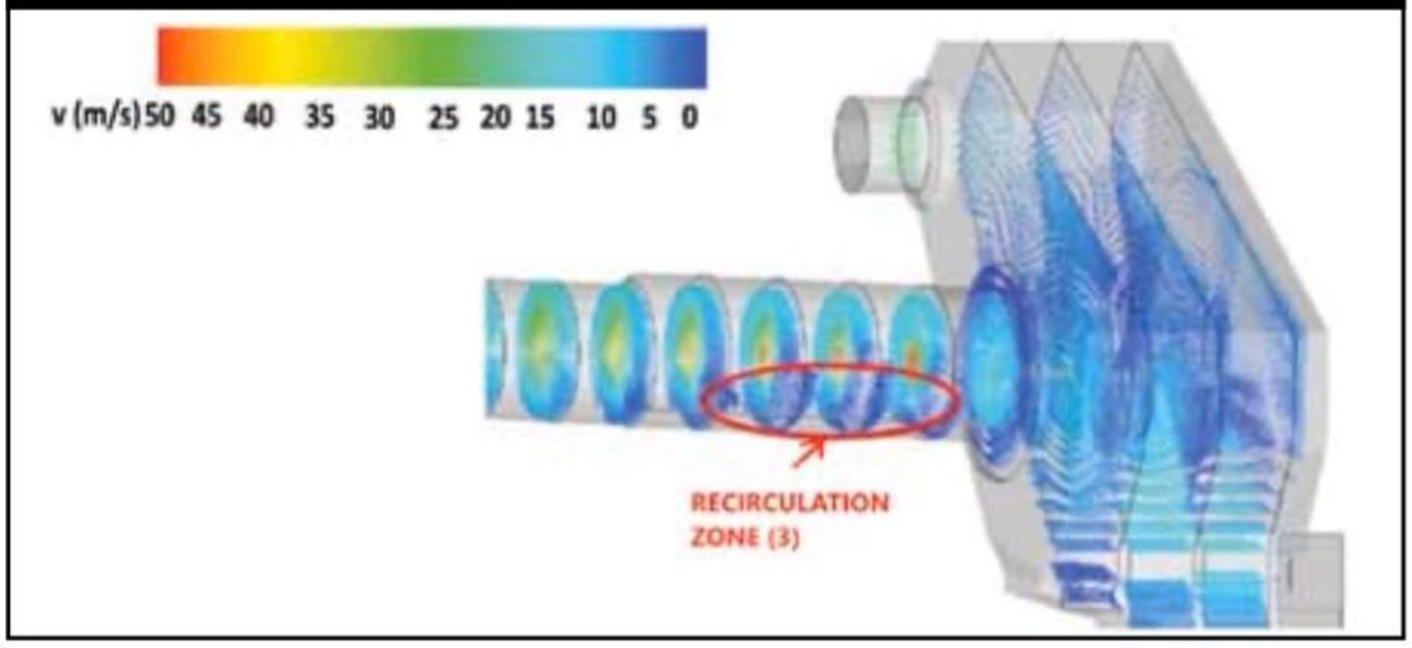


Table 2: clinker combinability temperature for FCaO (inputs = blue, outputs = red)

Plant with petcoke firing			Plant with less petcoke + selective quarrying		
CT	Air +90u (%)	Clinker LSF	CT	Air +90u (%)	Clinker LSF
1612	5	99	1467	2	98
MgO (%)	Raw meal +150u (%)	Clinker A/F	MgO (%)	Raw meal +150u (%)	Clinker A/F
2	5	2.3	2	2	1.7
Clinker FCaO (%)	Clinker fluorine (%)	Clinker SO_3 (%)	Clinker FCaO (%)	Clinker fluorine (%)	Clinker SO_3 (%)
0.5	0	1.5	1	0	1
Clinker MR	LP liquid at CT (%)	LP liquid at 1338 (%)	Clinker MR	LP liquid at CT (%)	LP liquid at 1338 (%)
1.9	25.6	16.5	1.3	24.7	21.1

CT to 1476˚C. Under these conditions, the clinker became much less dusty, the production more stable and snowmen issues eliminated.

Conclusion

To prevent or eliminate kiln balls and rings or snowmen, sticky dust, excess and low-viscosity LP liquid and SO_3 cycles must be minimised. Key guidelines to avoid kiln balls, rings and snowmen are:

- liquid at CT <26 per cent (value at actual CT)
- CT of <1500˚C – to avoid hard burning and high SO_3 cycle and sulpho-spurrite rings
- clinker Fe_2O_3 of <4.5 per cent – to avoid sinter rings and kiln balls
- no coarse calcite in the kiln feed to avoid spurrite rings
- a clinker MR <1.2, a VF SO_3 <2 and HM excess SO_3 <1 per cent to avoid dusty clinker, sulpho-spurrite rings and kiln balls
- kiln burner and calciner optimised to ensure that there are no reducing conditions as a result of the kiln burner or unburnt carbon >0.1 per cent in the hot meal to avoid poor clinker quality, rings and snowmen. ■