COMBATTING LIME KILN RINGING PROBLEMS AT THE ARAUCO CONSTITUCIÓN MILL

Eduardo Keim
Bioforest – Arauco
Concepción, Chile

Jorge Zuñiga and Felipe Irarrazabal
Celulosa Arauco y Constitucion SA
Constitución, Chile

Honghi Tran
University of Toronto
Toronto, ON, Canada

ABSTRACT

The lime kiln at the Arauco Constitución mill experienced severe ringing problems requiring it to be shut down for ring removal every 3 to 6 months. The mill controlled the problems by blasting ring deposits off during operation with its existing industrial shotgun and a newly installed Cardox liquid CO_2 cartridge system. Various ring blasting procedures were tested to determine the optimum ring location and thickness to blast, the optimum depth to insert the CO_2 cartridge into the kiln, and the most effective blasting frequency and sequence to employ. The best ring blasting strategy was found to be the weekly blasting operation alternated between the Cardox system and the industrial shotgun, with the blasting aimed at rings at about 28 m (92 ft) from the kiln discharge end, and the CO_2 cartridge inserted into the ring mass, 20 cm (8") away from the refractory brick surface. With this blasting strategy, the kiln has been able to operate nonstop between annual maintenance shutdowns.

BACKGROUND

The Constitución mill, one of the five Arauco Celulosa kraft pulp mills in Chile, is located near the Chilean shore about 360 km south of Santiago. The mill was built in 1976, upgraded in the 90's and is presently producing 950 metric tons/day of unbleached radiata pine pulp. Woodchips are cooked in a Rapid Heat Displacement batch digester system, which recirculates the hot black liquor from one cook to the next to improve the energy efficiency. Due to the production of two types of pulp with different alkali charges to the digesters, the quantity and quality of the liquor circulating around the chemical recovery system often vary.

The kiln was a Polysius unit built in 1976 and later modified by FLSmidth to the present dimensions of 3.2 m (10.5 ft) I.D. x 95 m (317 ft) in length. It is equipped with satellite product coolers, a chain drying section, an electrostatic precipitator (ESP) and a cyclone after the ESP. Originally designed to produce 200 tons/day of lime with an availability of 90% of CaO, the kiln has operated at 30% over design capacity, producing 260 tons/day of lime since the mill upgrade in the 90's. The fuel burned is a mixture of 60% No. 6 heavy fuel oil and 40% tall oil, along with stripper-off gases (SOG) from the evaporator foul condensate stripper, and non-condensable gases (NCG) from batch digesters.

Constitución lime kiln had a severe ringing problem. The rings consistently formed within 2 to 3 months after the annual maintenance shutdown and continued to grow until they became so large that the kiln needed to be stopped for ring removal. On average, rings needed to be removed twice a year. One was during the mill's maintenance shutdown and the other was unscheduled due to severe ringing. An unscheduled kiln shutdown typically costs the mill about $1 million US. The mill responded to the problems by:

1. Constantly monitoring changes in kiln shell temperatures and using the information to estimate the corresponding ring thickness with time;
2. Collecting ring samples at different locations during kiln outages and analyzing them for chemical composition and mechanical strength;
3. Analyzing kiln/causticizing plant operating data to examine the root causes of the problems; and

4. Installing a new Cardox liquid CO_2 cartridge system to blast away ring deposits, along with its existing industrial shotgun.

Results of chemical analysis of ring samples showed that they consisted of mostly $CaCO_3$, $CaSO_4$ and some CaO, typical for rings found in kilns that burn high sulfur-containing fuels such as No. 6 heavy fuel oil, petroleum coke, NCG and SOG [1,2]. The burning of NCG and SOG in the kiln with varying flow rates and compositions was believed to be the main cause of wide fluctuations of the burner flame and temperature that lead to rapid ring growths [3].

This paper discusses the experience of using the Cardox liquid CO_2 cartridge system together with the industrial shotgun to remove rings at Constitución, including the procedure for locating rings and monitoring their growth, the procedure for inserting a liquid CO_2 cartridge into the kiln and detonating it, and the effectiveness of the Cardox system in ring removal.

LOCATING RINGS

The increase in draft between the induced draft fan and the kiln hood at the discharge end, and the increase in amperage (power) of the kiln rotation motor were constantly monitored and used as an indication of ring growth. These signals, however, could indicate only the presence of rings in the kiln, but not where they were. In order to locate where the rings were, the kiln shell temperatures along the kiln length was periodically measured using a manual laser thermal gun. If a "cold spot" was found and it became progressively colder with time, it is likely that there was a ring formed in the kiln at that spot.

Figure 1 shows an example of the change in kiln shell temperature profiles with time, along the kiln length from 25 m (82 ft) to 64 m (210 ft) from the kiln front end. The "map" was constructed using the temperature data recorded with the thermal gun over a 3-month period in 2015. The color of each square area in the map represents a range of the shell surface temperature. Blue is where the shell surface temperature was below 100°C, red is where the temperature was between 100 and 200°C, green is where the temperature was between 200 and 300°C, and purple is where the temperature was the highest, 300 – 400°C.

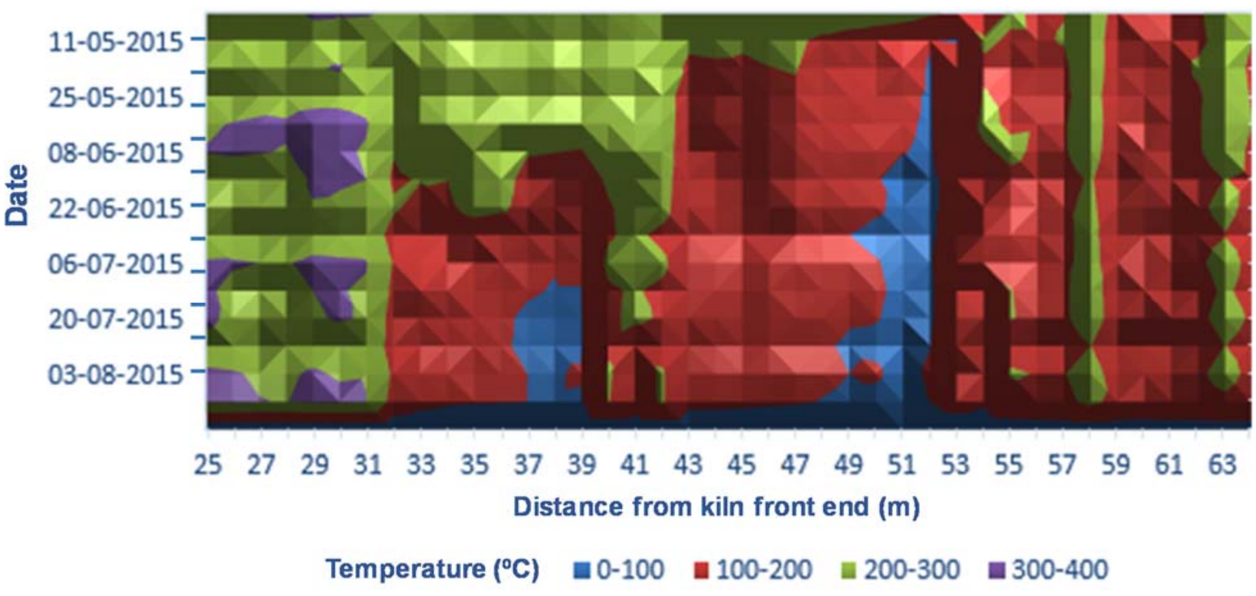

Figure 1. *Change in kiln shell temperature profiles during a ringing incident in 2015.*

As rings built up, they insulated the kiln shell from the hot flue gas, causing the shell temperature to drop. As a result, the color of the square area changed progressively from purple to green, to red, and then to blue as rings grew thicker with time. For this ringing incident, for example, the shell temperature at 32 – 40 m from the kiln front end decreased from 200 – 300°C (green) on May 11 to 100 – 200°C (red) on June 22. In a small region, the shell temperature decreased further to below 100°C (blue) and remained low in this temperature range until the kiln was shutdown for ring removal in August.

The change in kiln shell temperature profiles suggests that rings were formed initially at two locations (blue and red squares) between May and August 2015. They spread out and connected after 3 months of operation, forming a long, massive ring at about 30 – 60 m from the discharge end. This 30 m long ring had a thickness varying widely with location, from a few centimetres to almost 1.2 m.

RING REMOVAL PROCEDURES

The mill responded to the ringing problem from two fronts: 1) stabilizing the kiln/causticizing plant operations to minimize the flame temperature variation in the kiln and hence the rate of ring buildup, and 2) installing a Cardox system on the kiln shell to mechanically blast off ring deposits with pressurized liquid CO_2 cartridges.

Stabilizing process operations is an on-going improvement process at the mill in order to achieve the lime production target. Unfortunately, the variation in flowrate, moisture content, and sulfur content of the fuels burned in the kiln (i.e. SOG, concentrated non-condensible gases (CNCG), tall oil and No. 6 fuel oil) make it difficult to stabilize the kiln operation, which can contribute to the formation and hardening of ring deposits [1,3].

Since it was difficult to prevent rings from forming, the mill resorted to mechanical means for controlling ring growth. Several conventional methods were used, including: a) turning off the burner flame to thermally shock and crack the rings, b) shooting the rings with an industrial shotgun from the kiln discharge end, and c) increasing the use of limestone (lime rock) make-up to wear off the rings. While these methods helped control ring growth, they were unreliable and often ineffective.

The strategy for ring removal at Constitución involved the following steps:

1. Continuous Measurement of Kiln Shell Temperatures

An infrared imaging camera was installed in 2016 to continuously record the kiln shell temperature in order to locate where rings form and how they grow with time. The camera greatly improved the temperature measurements, providing online information on temperature distribution over the entire kiln shell surface, as opposed to only sporadic temperature readings obtained manually with the thermal gun. **Figure 2** is an example of an instantaneous thermal image of the kiln shell taken on July 1, 2016 at 11:47 PM when the kiln was clean without a ring inside.

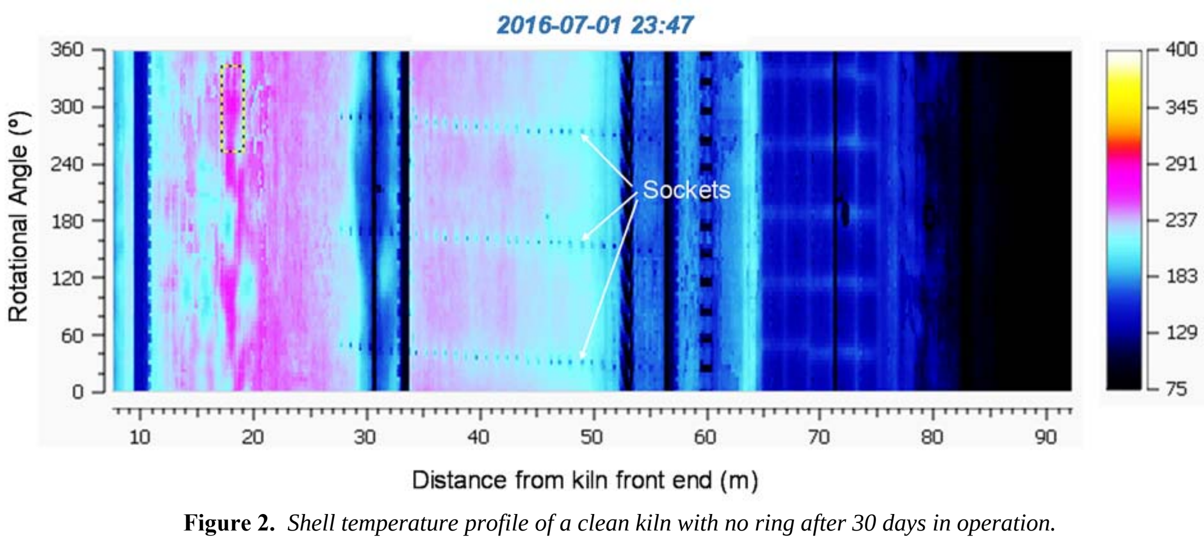

Figure 2. *Shell temperature profile of a clean kiln with no ring after 30 days in operation.*

2. Installation of Sockets for the Liquid CO_2 Cartridge System

Based on historical experience and the information obtained from the thermal laser gun, a total of 87 sockets were installed for the application of the Cardox ring blasting system during the 2016 annual maintenance kiln shutdown. These sockets were aligned in three rows, 29 sockets in each row placed at an equal distance in the radial direction (120° position), over a 28 m section along the kiln axis. Within each row, the distance between one socket to the next is 1 m. These three rows of sockets can be noted in Figure 2 as small blue dots starting at 28 m and ending at 56 m from the kiln discharge end. **Figure 3** shows a close-up picture of a socket and its cap, and how the sockets are aligned on the kiln shell.

Figure 3. *Sockets over the shell in the lime kiln.*

3. Monitoring the Ring Growth

At a constant burner flame (or flue gas) temperature inside the kiln, the shell temperature at a given location would decrease if there is a ring built up at that location. The infrared camera would consequently register a "cold" (lower shell surface temperature) area on the shell. **Figure 4** shows a thermal image of the kiln shell taken on August 29, 2016 at 11:14 AM, about 2 months after the kiln was in operation. Comparing this image to that shown in Figure 2 (when the kiln was clean) suggests that there were two separate rings formed on the kiln wall: one was at 28 to 33 m and the other at 38 to 47 m from the discharge end.

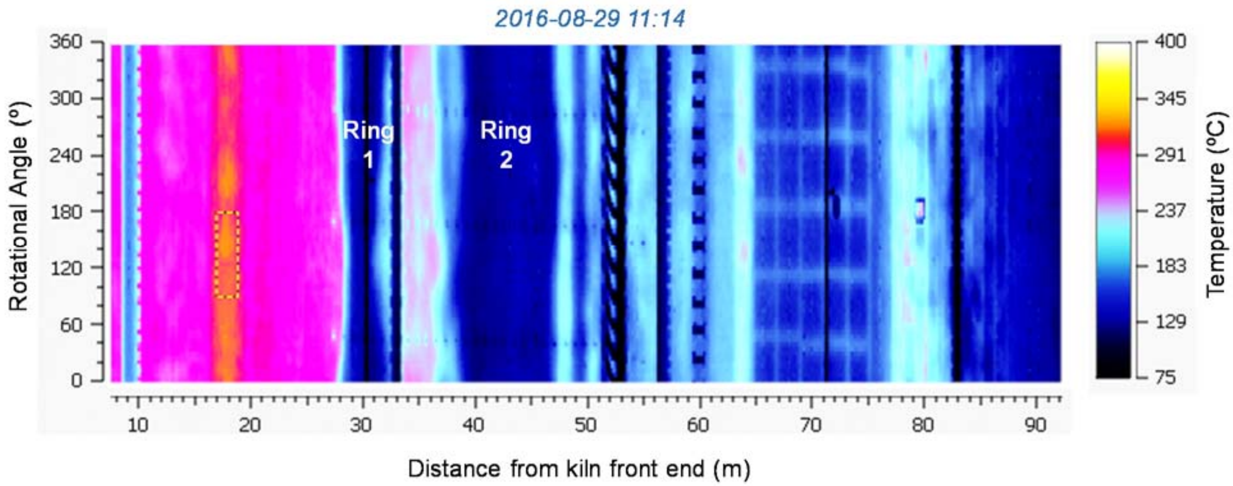

Figure 4. *Infrared image of kiln shell temperature on August 29, 2016 at 11:14 AM.*

4. Choice of Sockets to Use

The question is which of the 87 sockets should be drilled through in order to insert the liquid CO_2 cartridge to do the blast? Typically, the flue gas temperature of the kiln increases rapidly reaching a maximum value at about 18 m from the discharge end (near the tip of the burner flame), and then decreases toward the feed end. This change in flue gas temperature means that at different locations along the kiln axis, the same color (i.e. same shell temperature) may indicate a different ring thickness inside. Thus, when comparing two blue spots with the same intensity in Figure 4, the one on the left (with a higher flue gas temperature inside) should be covered by a thicker ring than the one on the right (with a lower flue gas temperature). Using the approximate flue gas temperature profile obtained from previous CFD (computational fluid dynamic) modelling work and the kiln shell temperature profile shown in Figure 4, an energy balance can be performed to estimate the ring thickness at different locations. The results are then used to decide which sockets are more suitable to use.

5. Blasting Procedure

Once a socket has been chosen to do the blast, the kiln rotation is stopped, along with the mud feed to the kiln and the fuel to the burner. A ring cleaning crew of 4 to 6 workers clears the area around the socket, sets up necessary equipment, uncaps the socket, and drills a hole through the socket, the brick and the buildup (**Figure 5A**). A liquid CO_2 cartridge is then inserted into the hole and securely mounted (**Figure 5B**). The cartridge is connected to a remote trigger with electrical wires and detonated.

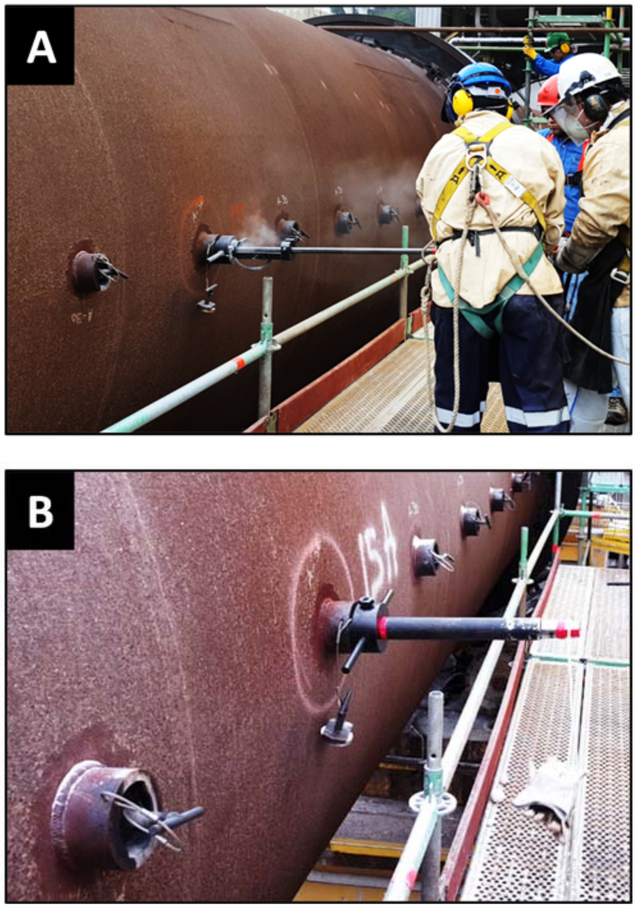

Figure 5. *A) a ring cleaning crew drilling a hole through a socket into the refractory brick and ring buildup, and B) a liquid CO_2 cartridge securely placed in the socket and ready to be detonated.*

The installation procedure and use of the liquid CO_2 cartridge system have been well described elsewhere [4]. The system has been used by many mills to efficiently and cost-effectively remove rings. It involves cartridges filled with liquid CO_2. When detonated with an electrical spark, the chemical heater around the cartridge instantly converts the liquid CO_2 into gas. This causes pressure to buildup inside the cartridge until it ruptures a disc located at the cartridge tip, ejecting the CO_2 gas through two opposing discharge nozzles. The ejected gas is powerful enough to blast the nearby ring off the kiln wall.

The experience at Constitución, however, is that the blast was seldom able to remove the ring right away. It only partially broke, cracked and weakened the ring, which then collapsed a few days after the kiln was back in operation. In some cases, additional blasts using the existing industrial shotgun were needed to accelerate the removal process.

IMPROVED BLASTING PROCEDURE

While liquid CO_2 cartridges are easy to use, using them effectively to remove rings requires good strategies, proper procedures and experience. Rings may form so massively that the first CO_2 cartridge detonation may not satisfactorily remove them. Based on experience, we developed an improved blasting procedure in house, which depends on the location and size of the ring involved.

Figure 6 schematically shows how the ring thickness changes with location in the kiln after 8 months of operation. The buildup was not uniform along the kiln length. There was little buildup in some sections and massive buildup in others. The first blast was carried out at the end of September 2016 and repeated every two weeks until the annual maintenance shutdown in January 2017 when the kiln was cleaned and inspected.

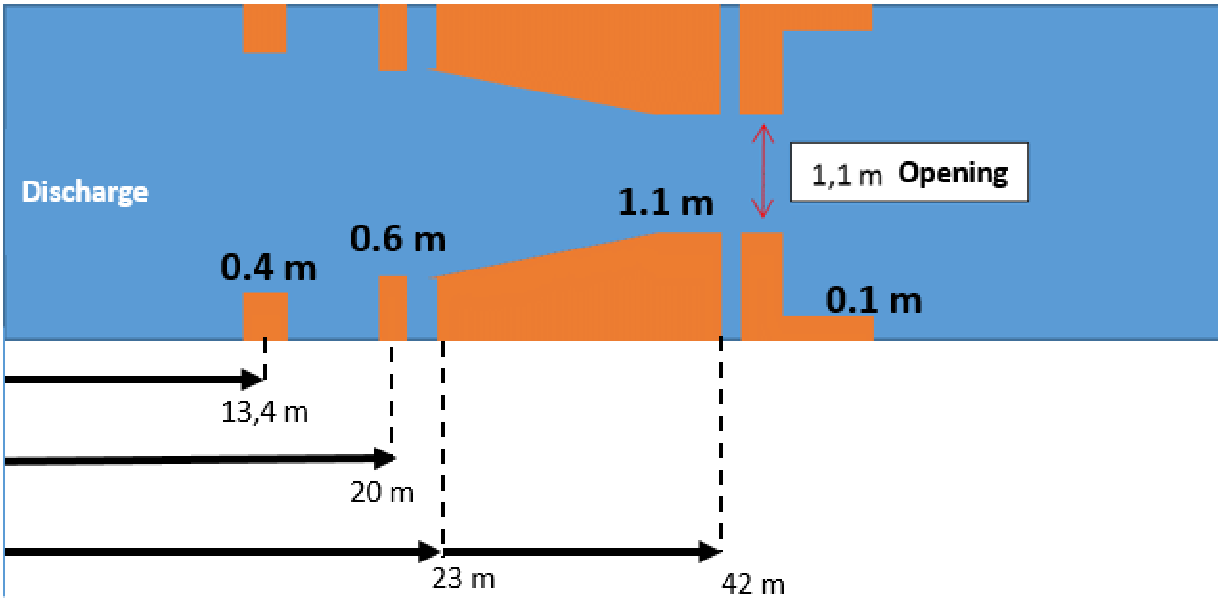

Figure 6. *Ring thickness observed during the January 2017 maintenance kiln outage.*

Figure 7 shows rings formed at 23 and 43 m from the kiln discharge end. Despite repeated blasting, only holes were made in the rings (**Figure 8**). The liquid CO_2 cartridge system was simply not effective enough to cause rings to fall and be removed.

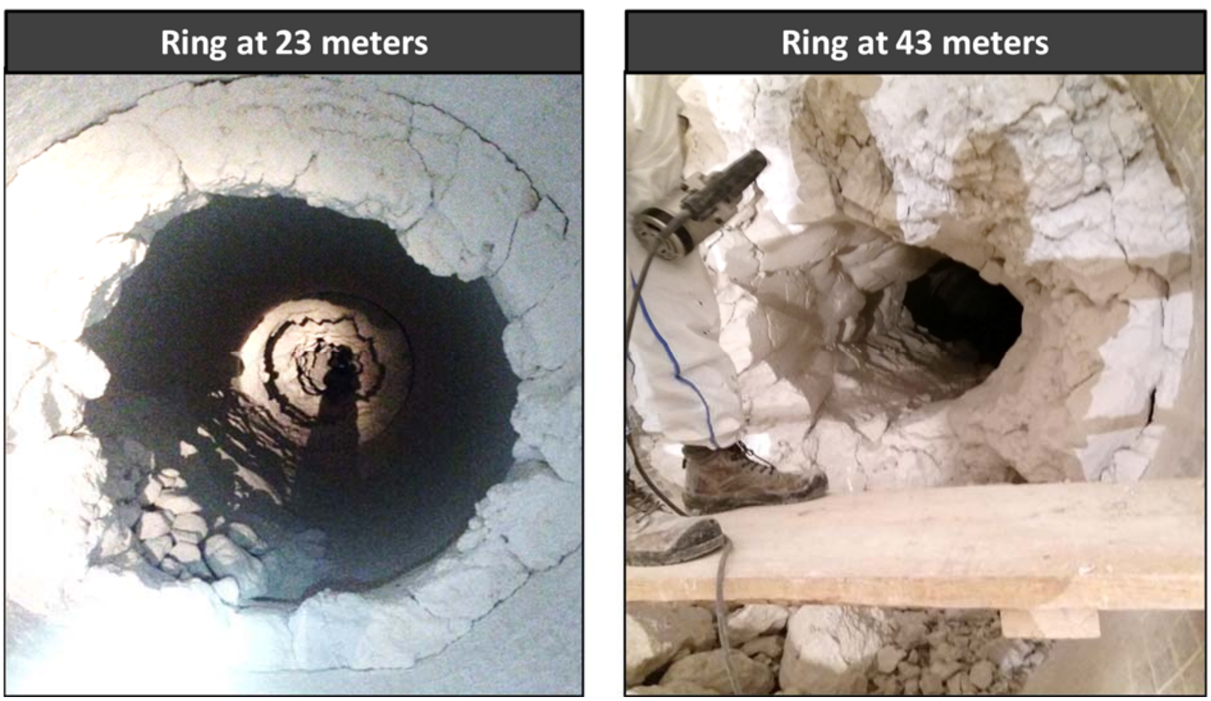

Figure 7. *Rings form at 23 and 43 meters from the discharge end.*

Figure 8. *Holes formed in rings as a result of liquid CO_2 blasts.*

Figure 9 schematically shows how holes might form in the ring as a result of blasting. As the CO_2 cartridge is inserted into the ring and detonated, the force produced by the blast should ideally shatter the ring apart causing it to collapse. But if the blast force is not strong enough, it can only fracture or remove a small portion of the ring. The debris subsequently falls out as the kiln rotates after it is back in operation, leaving behind a hole in the ring.

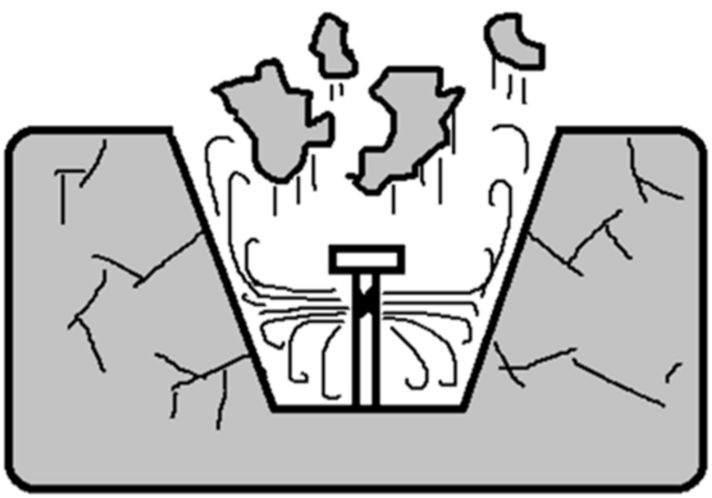

Figure 9. *A hole may form in a ring if the blast force generated by the liquid CO_2 cartridge is not sufficiently strong.*

Inspection of refractory bricks after rings were removed showed no indication of brick damage caused by blasting. The failure patterns suggested that most brick damage was sustained during hole drillings (**Figure 10**).

Figure 10. *Brick damage incurred during drilling.*

An improved hole-drilling practice was subsequently devised to minimize brick damage. This involved both row and column drillings. Row drilling refers to drills that are made parallel to the kiln shell, while column drilling indicates drills that are made normal to the shell (**Figure 11**).

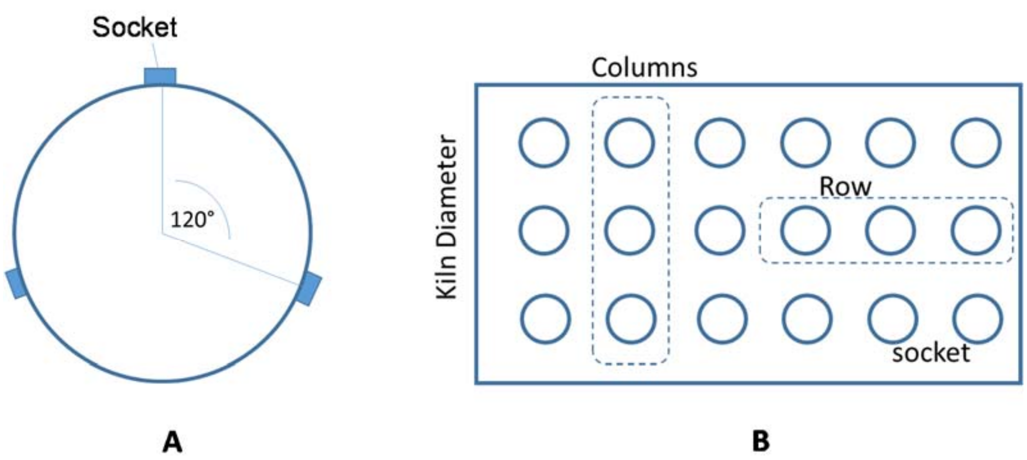

Figure 11. A) Cross section of the kiln through a socket plane; and B) Distribution of sockets along the kiln length.

Numerous tests were performed to examine the optimum depth for placing the CO_2 cartridge into ring deposits. The results showed that the best depth to achieve the most efficient ring removal and the least brick damage was when the tip of the CO_2 cartridge was at least about 20 cm (92 ft) away from the brick surface (**Figure 12**).

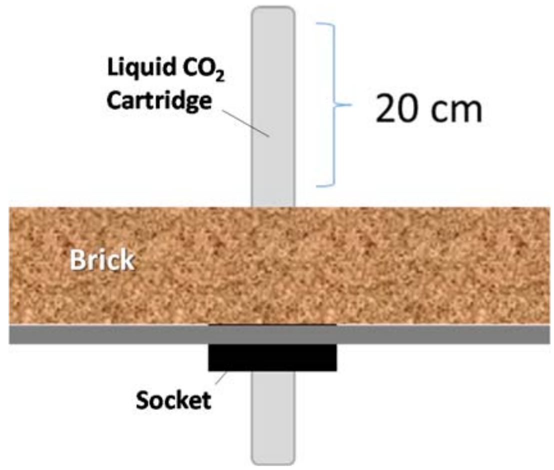

Figure 12. *Optimum distance from the liquid CO_2 cartridge discharge to the brick surface.*

An industrial shotgun was also used together with the liquid CO_2 cartridge system, but it was only good for removing rings at about 28 m (92 ft) from the kiln discharge end.

Prior to 2017, only the industrial shotgun was used to remove rings. The shotgun was aimed at only one location at a time and about 2000 shots were fired for the whole event. Although this approach did not completely remove the ring, it helped make the opening larger for the lime to pass through, as schematically shown in **Figure 13**. Understandably, it was more effective for controlling rings that were close to the discharge end than those located further back toward the feed end.

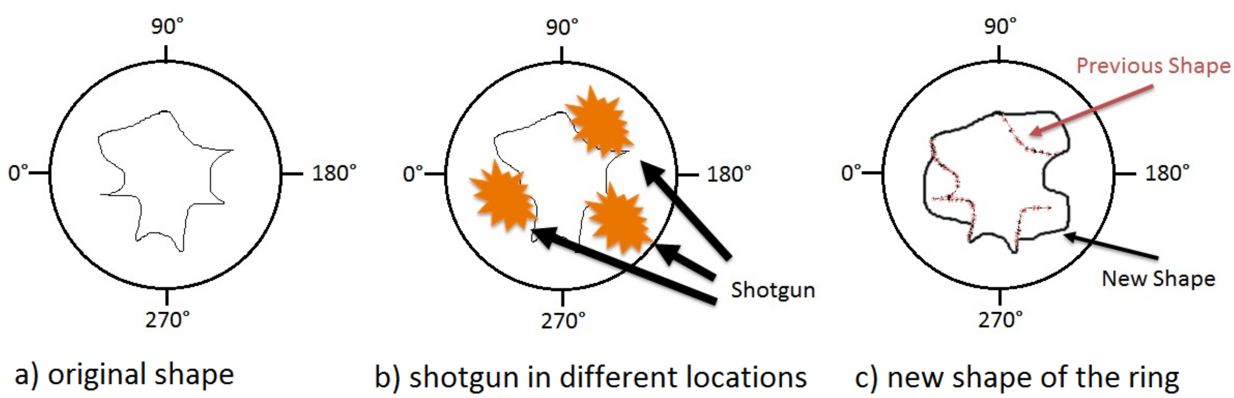

Figure 13. *Strategy for removing rings using shotgun before 2017.*

After the installation of the Cardox system and until the end of 2017, the blasting sequence was through the sockets along the kiln circumference (column drilling in Figure 11) with a fixed depth of 20 cm from the refractory brick surface. As with the industrial shotgun, this blasting strategy was not able to remove the ring effectively as shown in **Figure 14**.

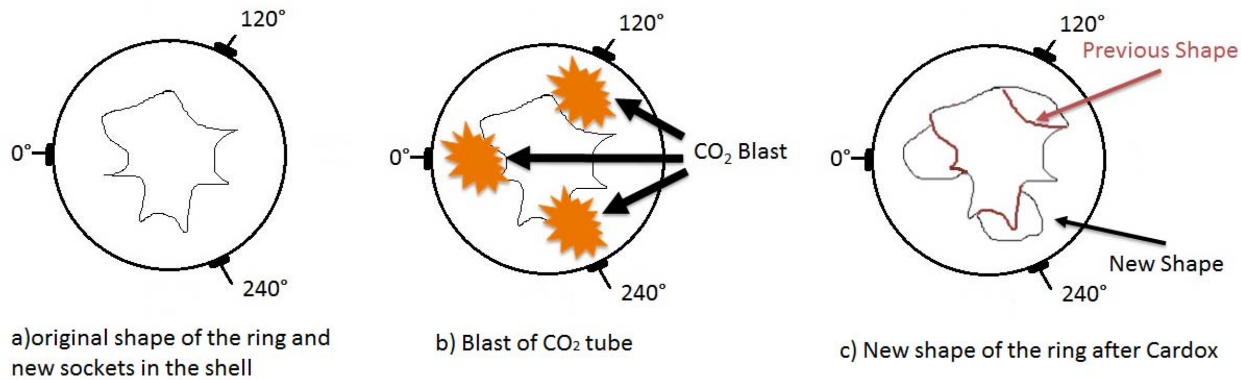

Figure 14. *Cardox strategy to remove the ring.*

After testing various ways of blasting, the best strategy for the liquid CO_2 cartridge application was found to be blasting in the row direction, i.e. along the kiln axis. For rings that were thicker than 50 cm, a minimum of 3 blasts at 2 different depths were needed. A week after the detonation, the ring was blasted again, together with the shotgun aiming at the same position. The combined use of shotgun and liquid CO_2 cartridge blasts greatly improved the removal of the rings a few days after the kiln was back in operation. **Figure 15** explains the new strategy used by the mill.

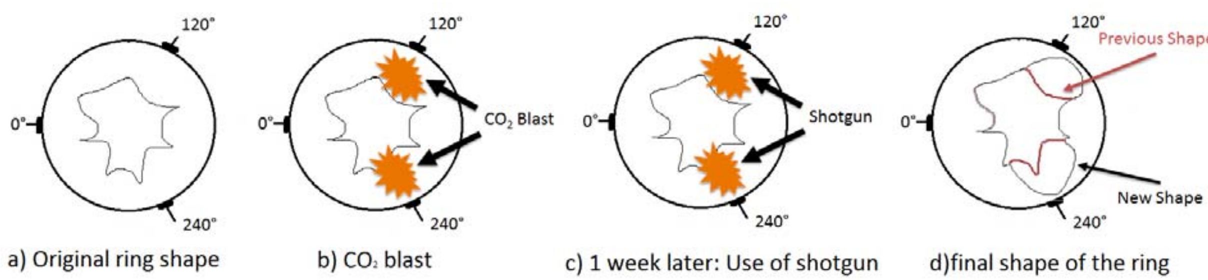

Figure 15. *New strategy combining CO_2 tubes and shotgun.*

This strategy has been implemented since the beginning of 2018. With this blasting strategy, the kiln can now run nonstop between annual maintenance shutdowns, substantially reducing the costs associated with ring removal and lime replacement during unscheduled shutdowns.

SUMMARY

Arauco Constitución mill experienced severe ringing problems in its lime kiln for years. The mill responded to the problems by constantly monitoring the ring growth based on changes in kiln shell temperature with time and installing a new Cardox liquid CO_2 cartridge system and using it together with its existing industrial shotgun to blast away the ring deposits.

Various ring blasting protocols were tested including the optimum ring location and thickness to blast, the optimum depth to insert the CO_2 cartridge into the kiln, and the most effective blasting frequency and sequence. The change in kiln shell temperature before and after each blast was used to determine the effectiveness of the removal process. The best ring removal strategy was found to be the weekly blasting operation alternated between the Cardox system and the industrial shotgun. The blasting should aim at rings at about 28 m (92 ft) from the kiln front end, and the CO_2 cartridge should be inserted into the ring mass, 20 cm (7.8") away from the refractory brick surface. This blasting strategy helps prolong the kiln operating time between annual maintenance shutdowns, substantially reducing the costs associated with ring removal and lime replacement.

This strategy has been implemented since the beginning of 2018. With this blasting strategy, the kiln can now run nonstop between annual maintenance shutdowns, substantially reducing the costs associated with ring removal and lime replacement during unscheduled shutdowns.

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Gateway to
the Future

Combatting Lime Kiln Ringing Problems at the Arauco Constitución Mill

Eduardo Keim
Bioforest – Arauco, Concepción, Chile

Jorge Zuñiga and Felipe Irarrazabal
Celulosa Arauco y Constitucion SA, Constitución, Chile

Honghi Tran
University of Toronto, Canada

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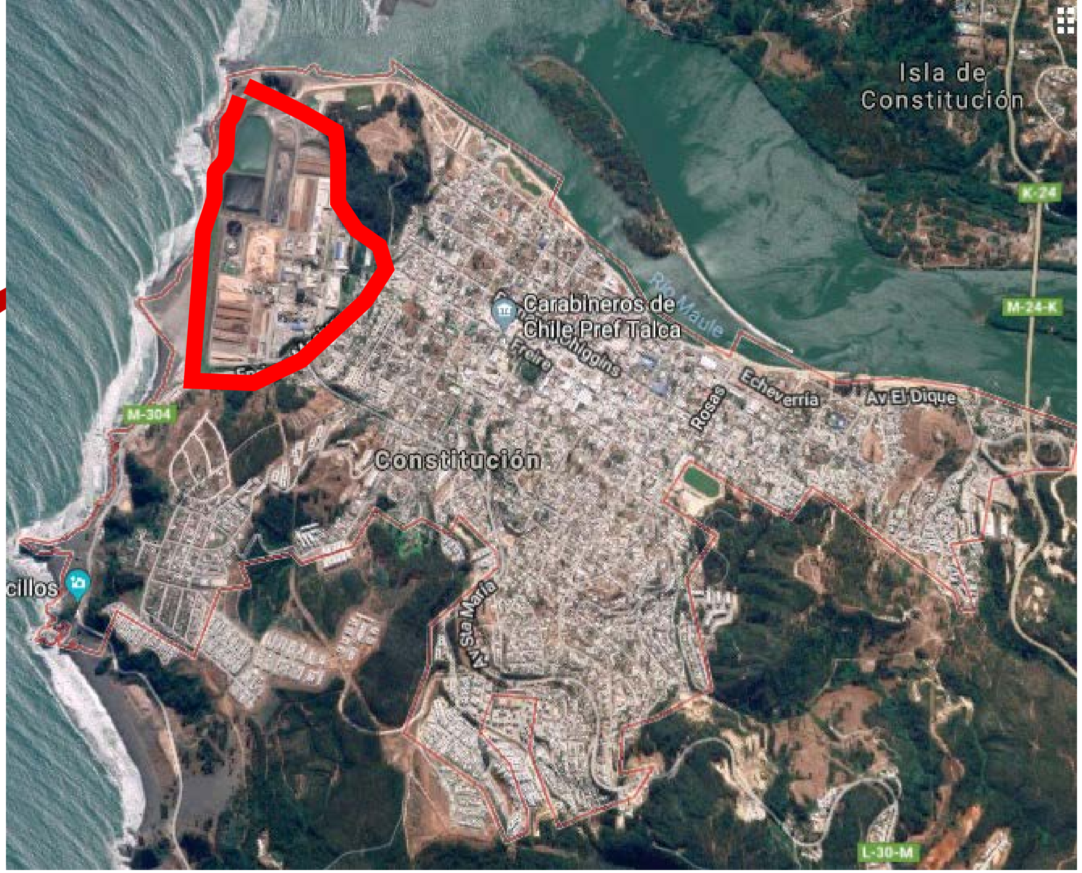
Constitucion town

Population: 46068 hab.
Area: 1.344 km^2

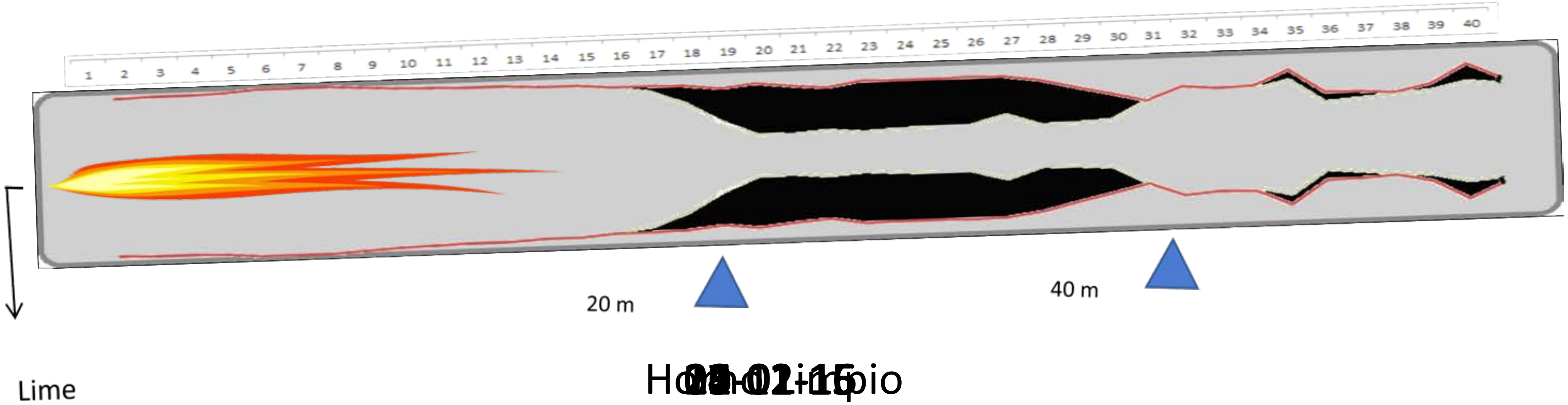


Constitucion mill

330.000 ADt/y Brownstock pulp
Built: 1970
RHD Cooking technology
1400 tds/d to RB

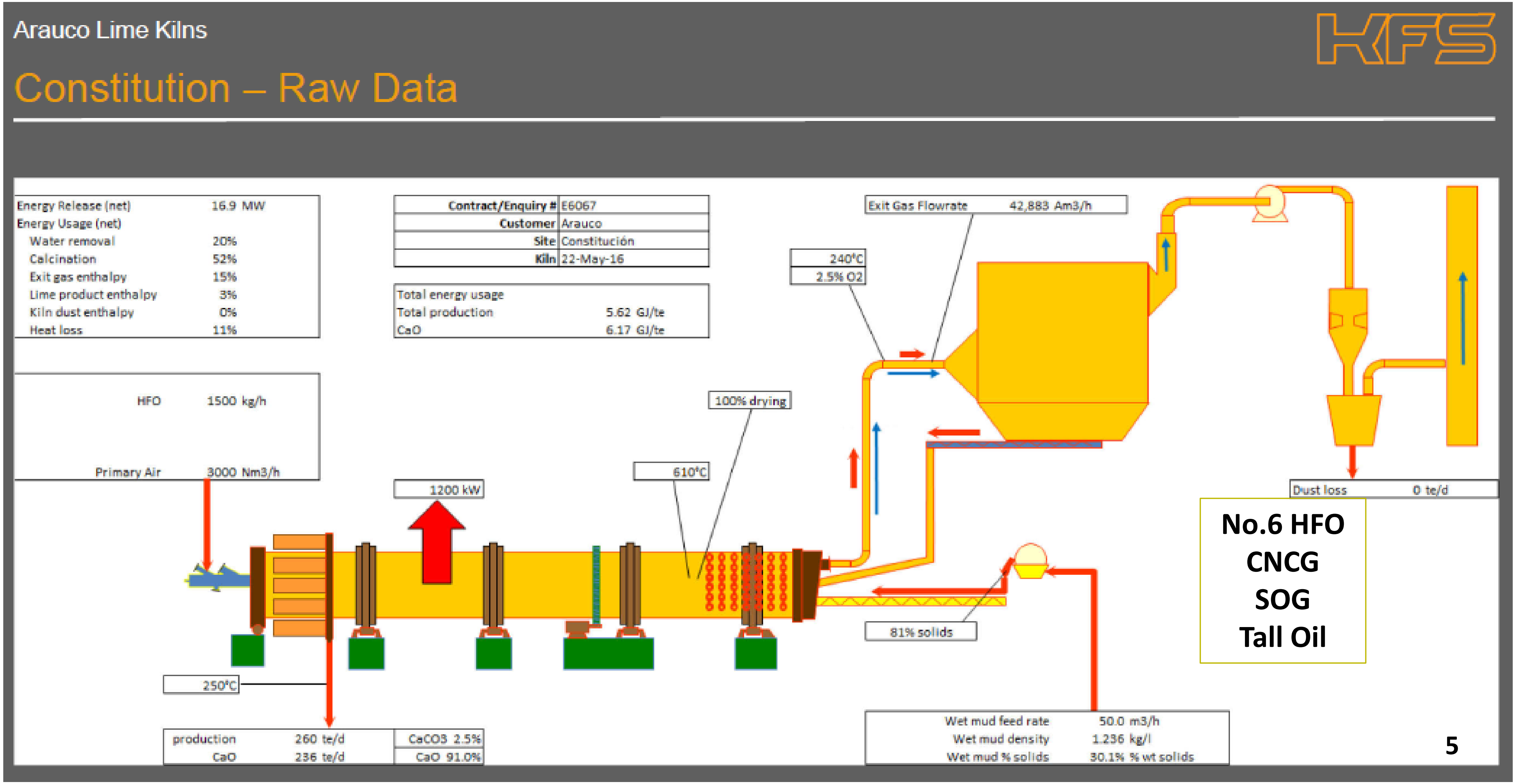
The problems:
Costing ~1 million USD/each shutdown for ring removal

Ring growth after 2015 annual scheduled shutdown



26/11/15 – 19/02/16

Lime Kiln Characteristics



Strategy to Remove Lime Kiln rings

Mechanical Removal

- Identify technology suppliers (Cardox)
- Strategy to use technology in Lime Kilns
- Lime Kiln dimensional stability
- Install system and use in improve operation.

Root Cause

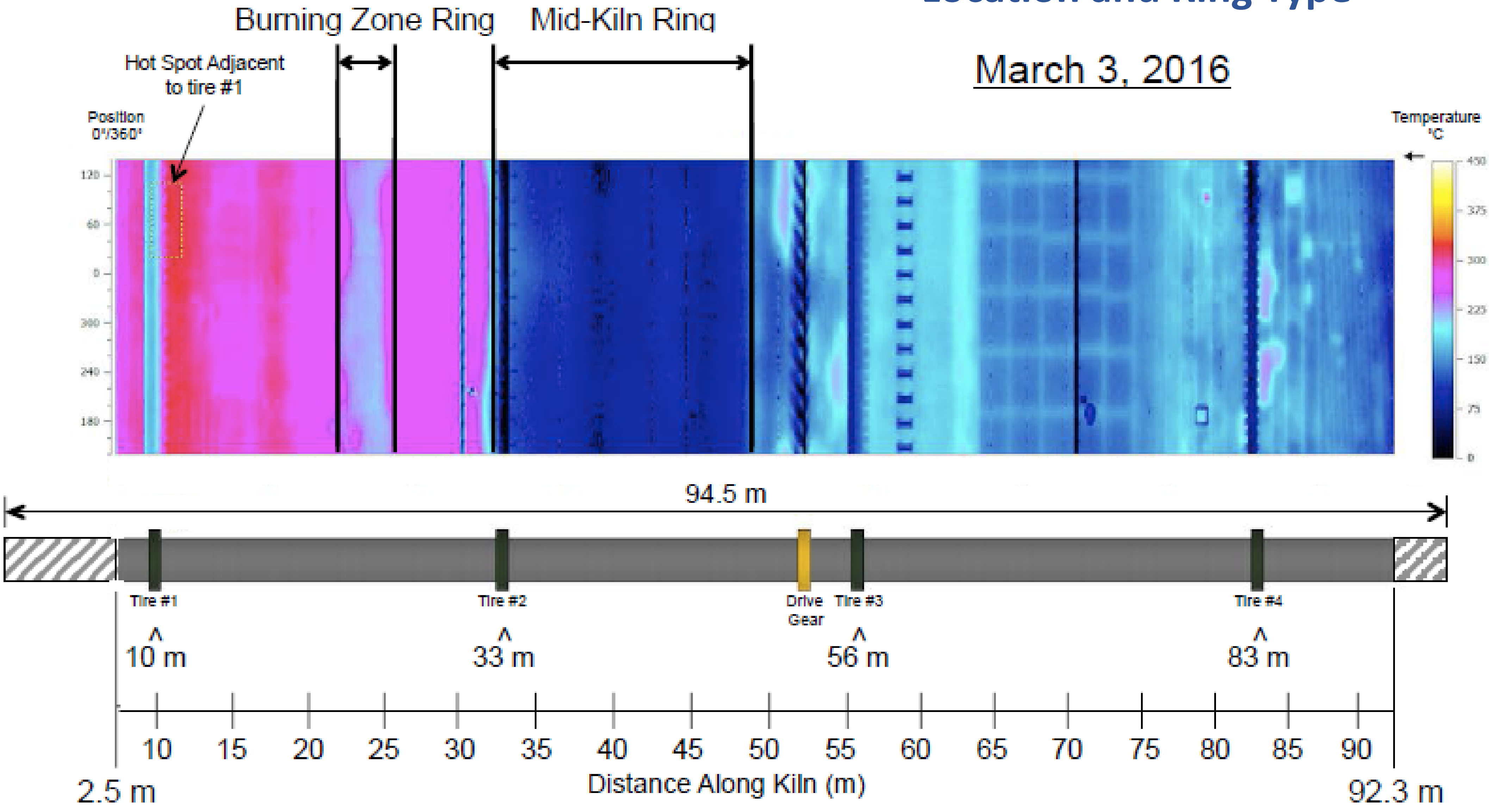
- Operational Parameter analysis
- Ring sampling and analysis
  - Different rings
  - Different locations
- Lime kiln model

Results and Discussion

Root Cause

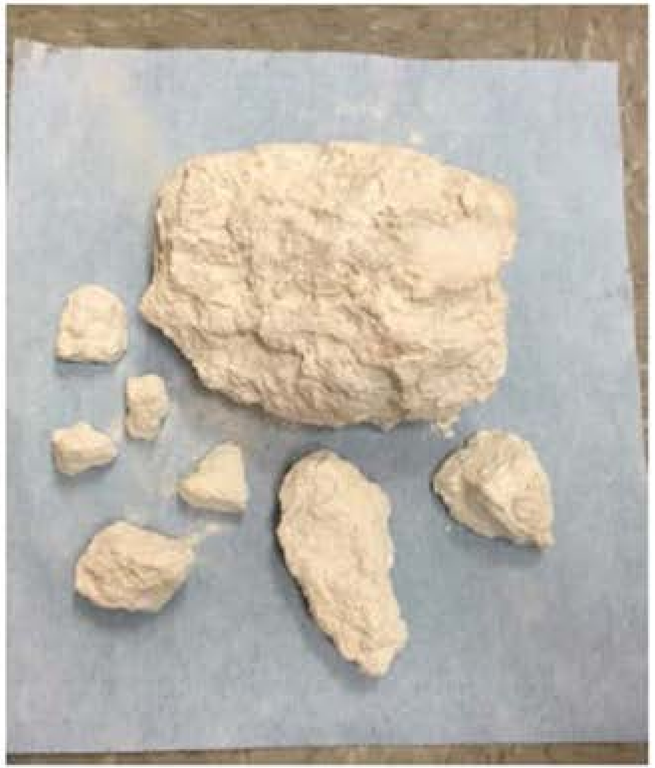
Location and Ring Type

March 3, 2016

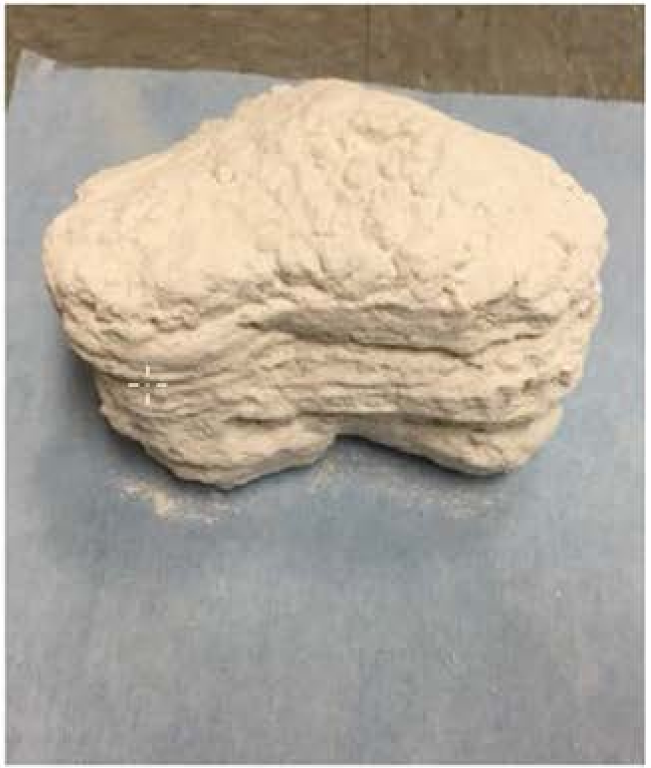


Root Cause

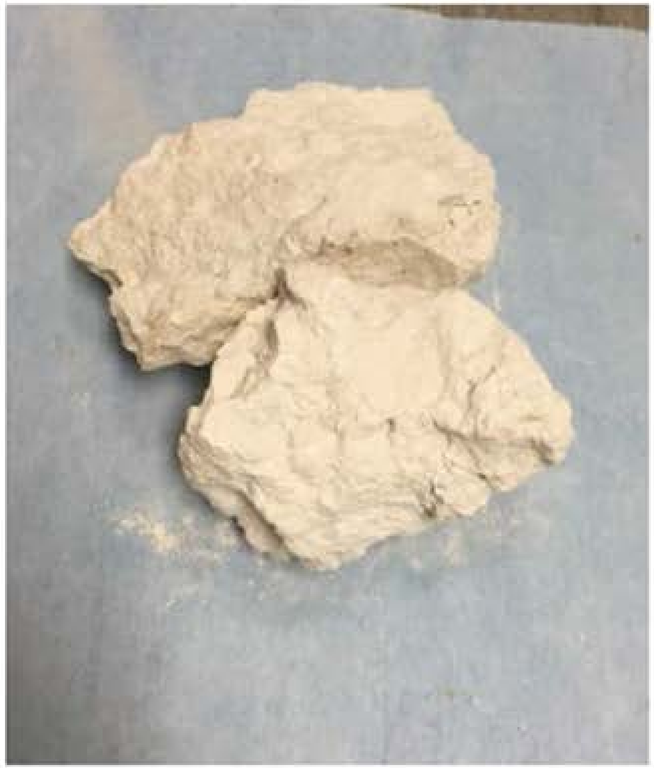
Sample 1
Front Ring
(hot end)



Sample 2
Middle of the Ring

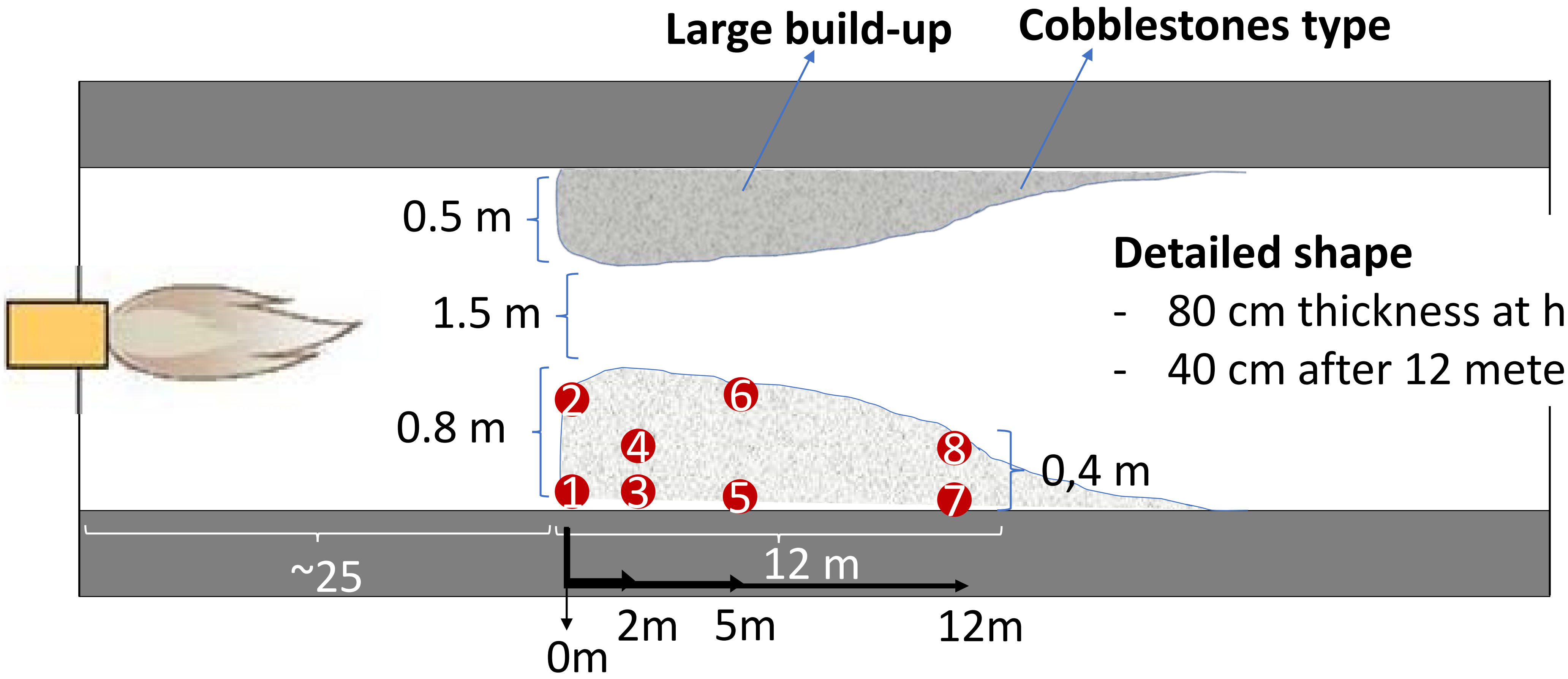


Sample 3
Back Ring
(cold-end)



Ring Sampling – February 2018 Kiln Shutdown

Ring and samples location



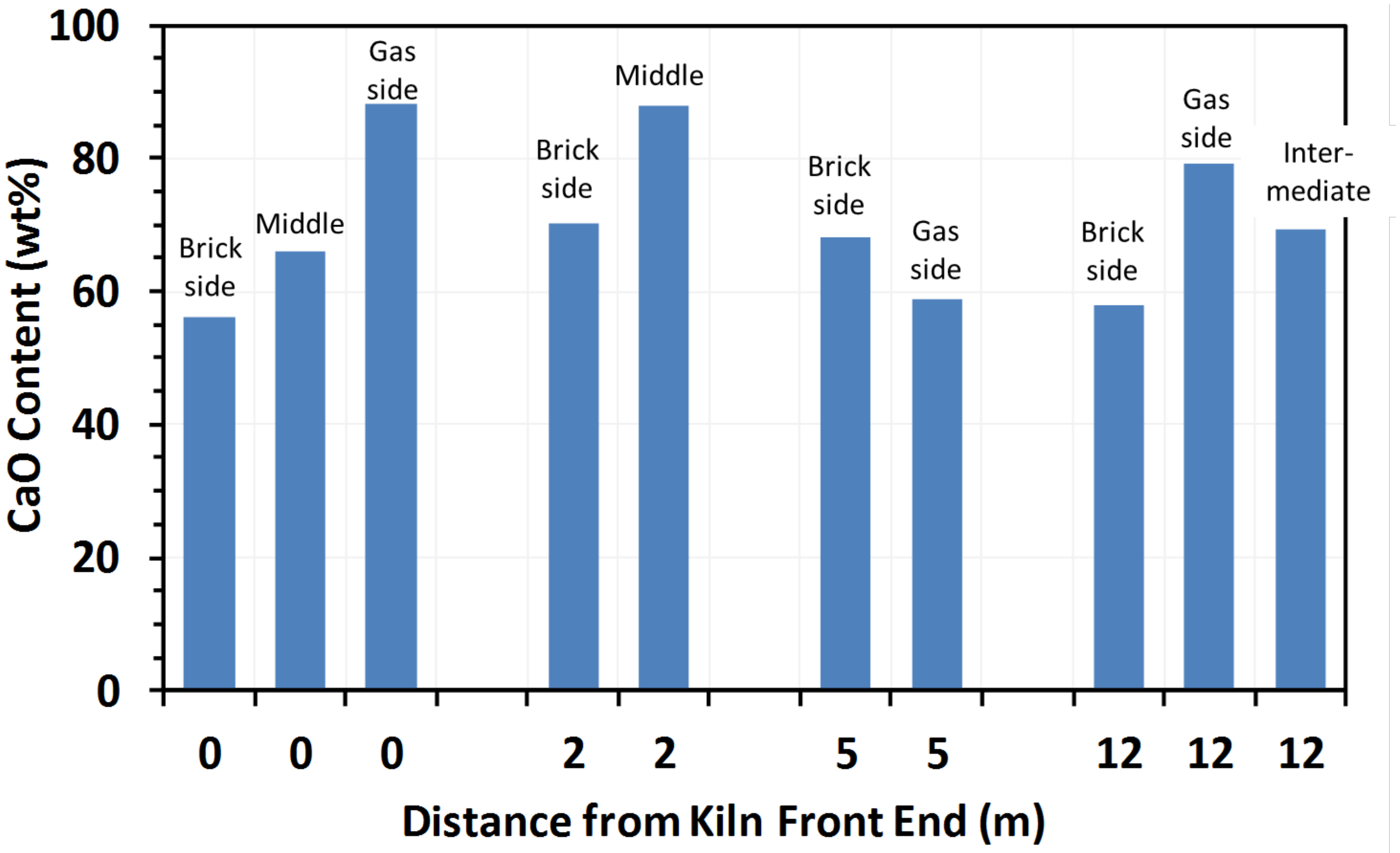
Detailed shape

- 80 cm thickness at hot side
- 40 cm after 12 meters

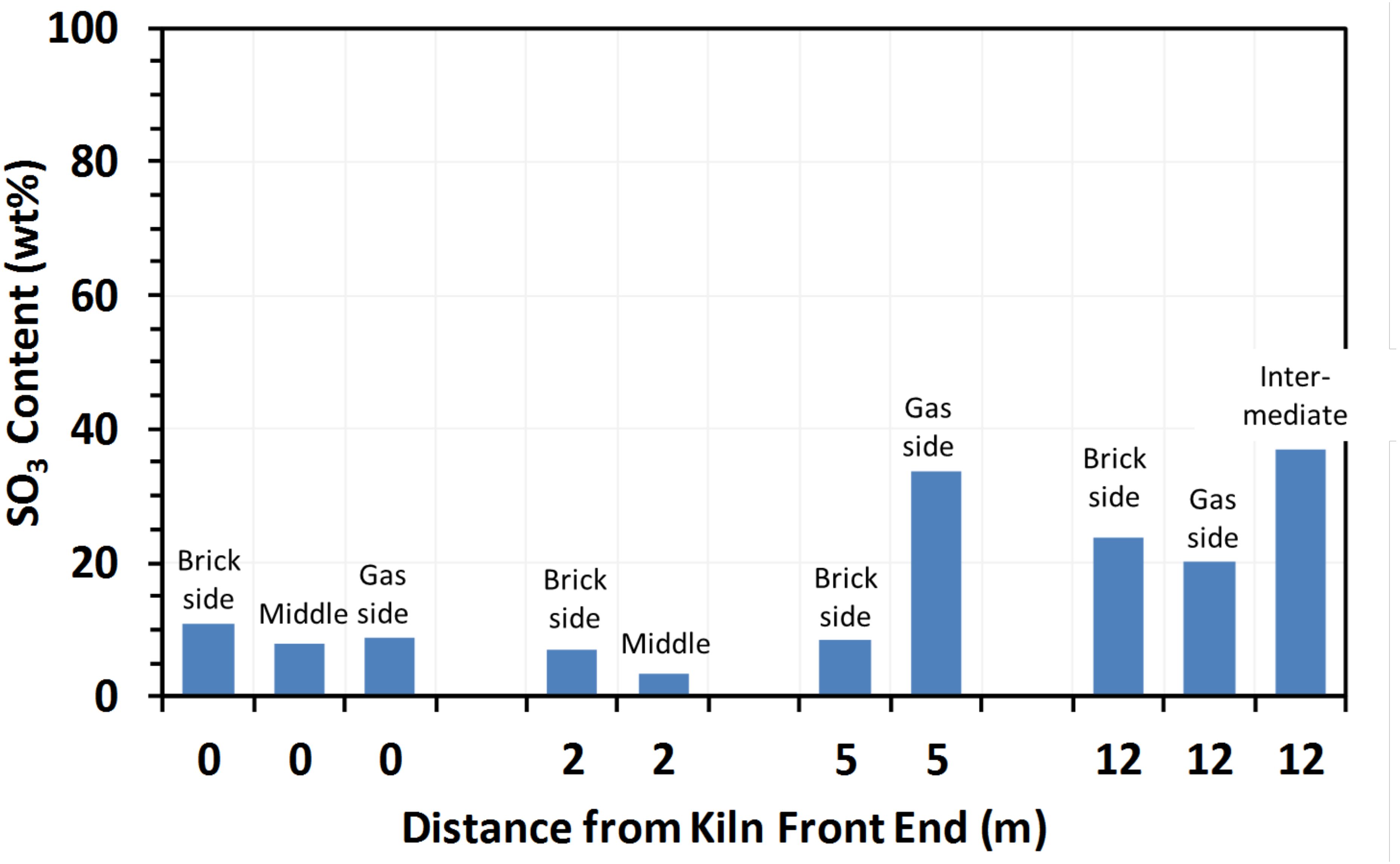
4 samples (0, 2, 5 and 12 m from front of ring) and 2 levels of sampling

“Normal ring” is located at 30 - 50 m from the lime discharge

CaO Content in Ring Deposits



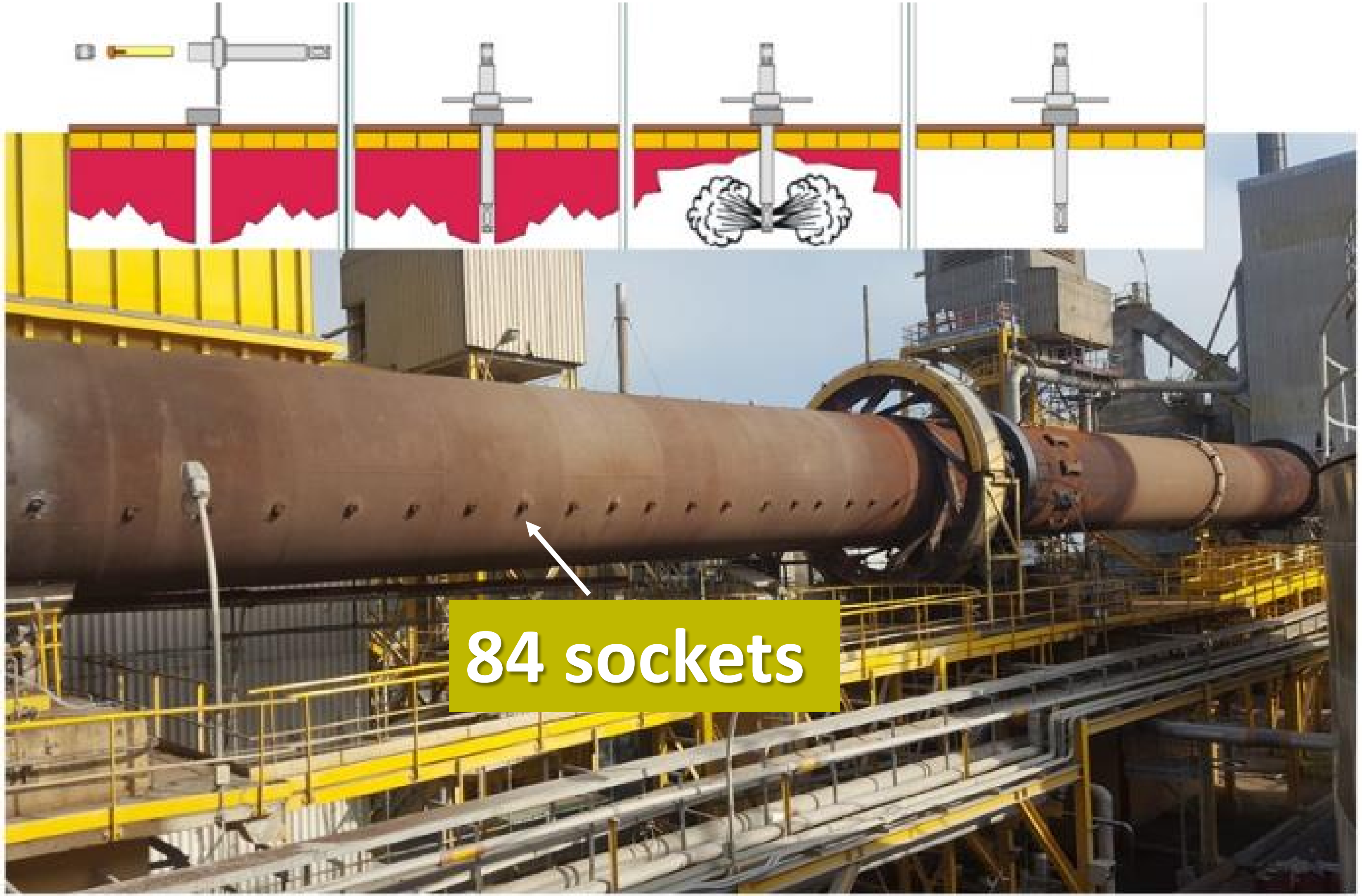
Sulfur Content in Ring Deposits



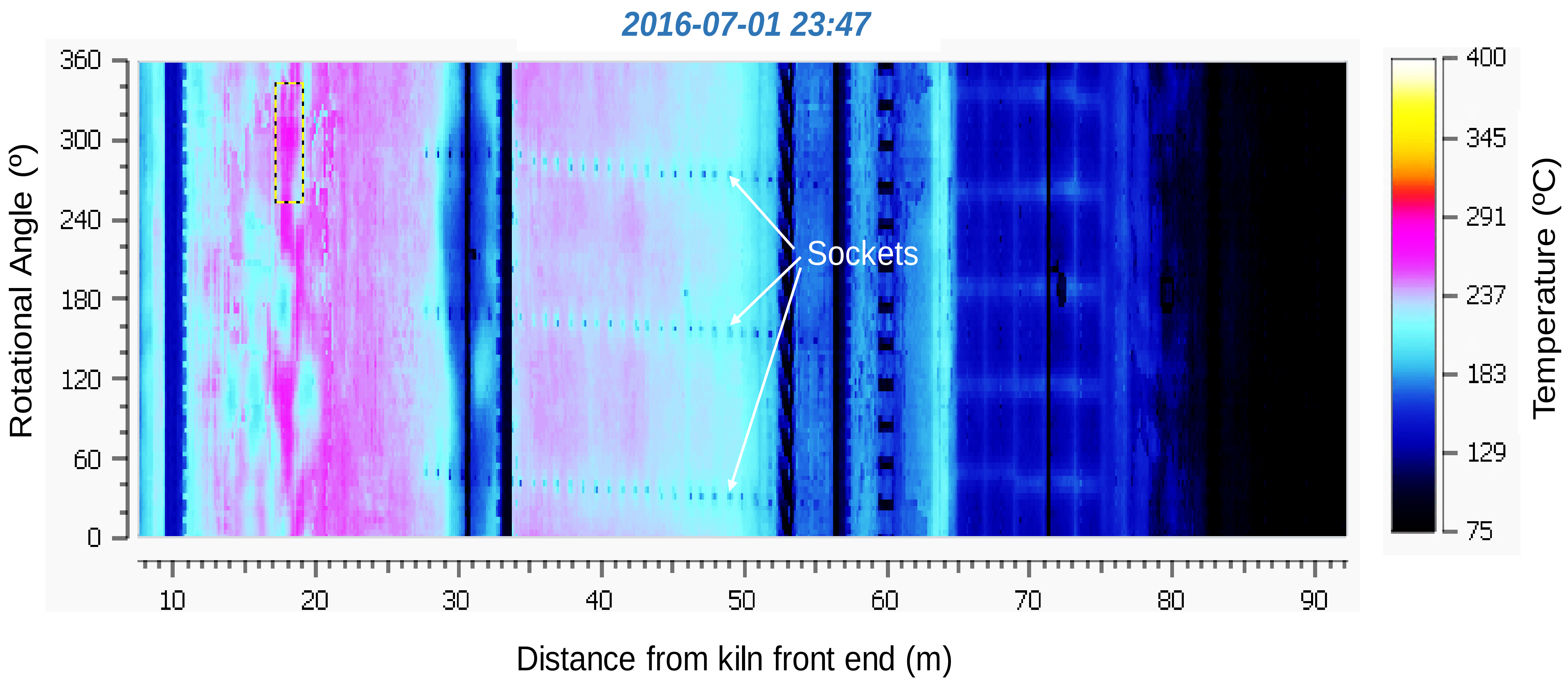
Implications

- Unstable operation → ring formation via "Recarbonation"
  - Sulfation enhanced ring deposit strength
- On-going solution to the problems is to stabilize kiln and recaust operation
  - Ensure good makeup lime quality
  - Optimize/minimize process variations
- In the meantime, install a Cardox CO_2 cartridge system on the kiln shell to mechanically remove rings when needed

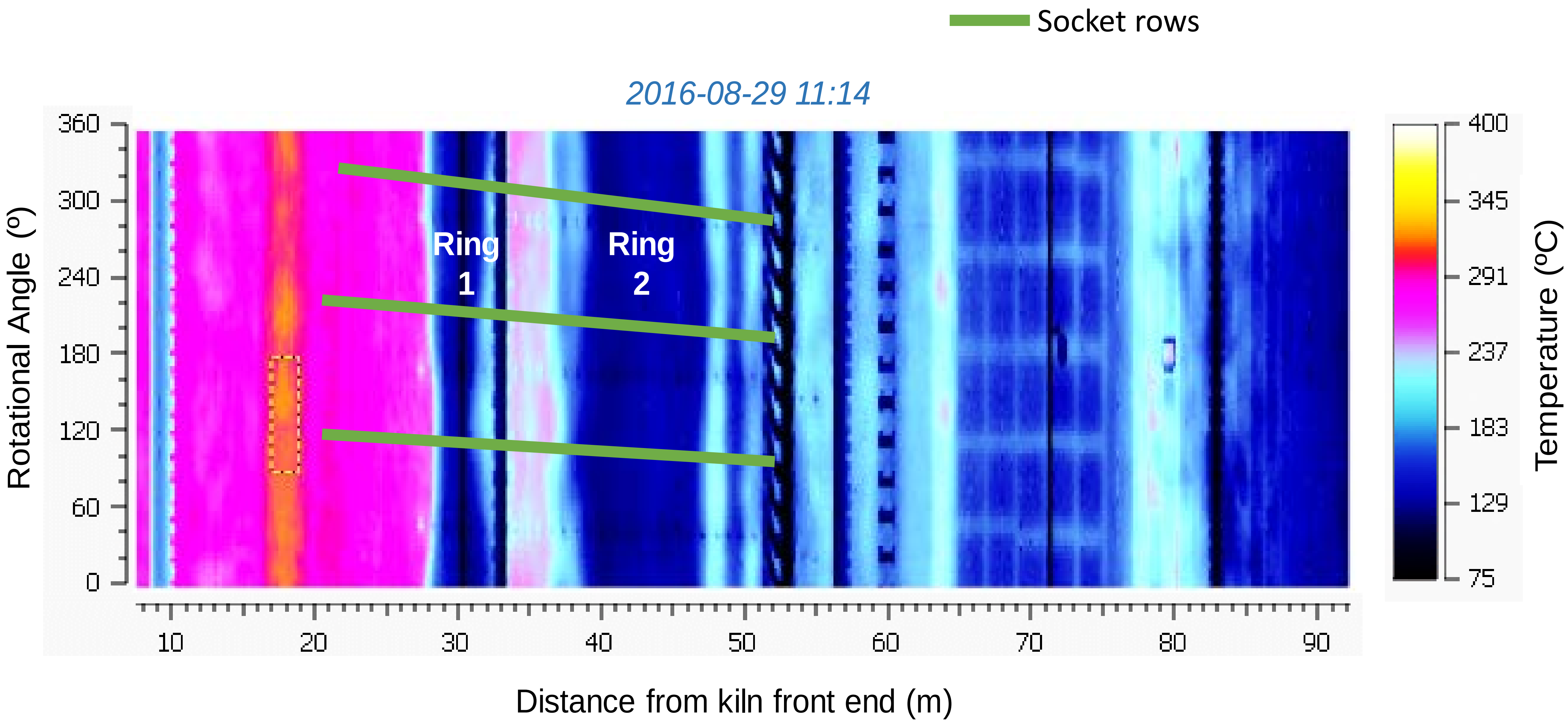
Installing Sockets for Inserting Cardox CO_2 Cartridges



Baseline - Location of sockets on kiln shell



After 2 months of operation



Ring Removal Operation

<u>PROCEDURE</u>

1. Stopped the kiln
2. Identified locations (sockets) to drill
3. Drilled through the bricks into ring
4. Inserted the CO_2 cartridge
5. Detonated
6. ……. and prayed that it works ….

It didn't!

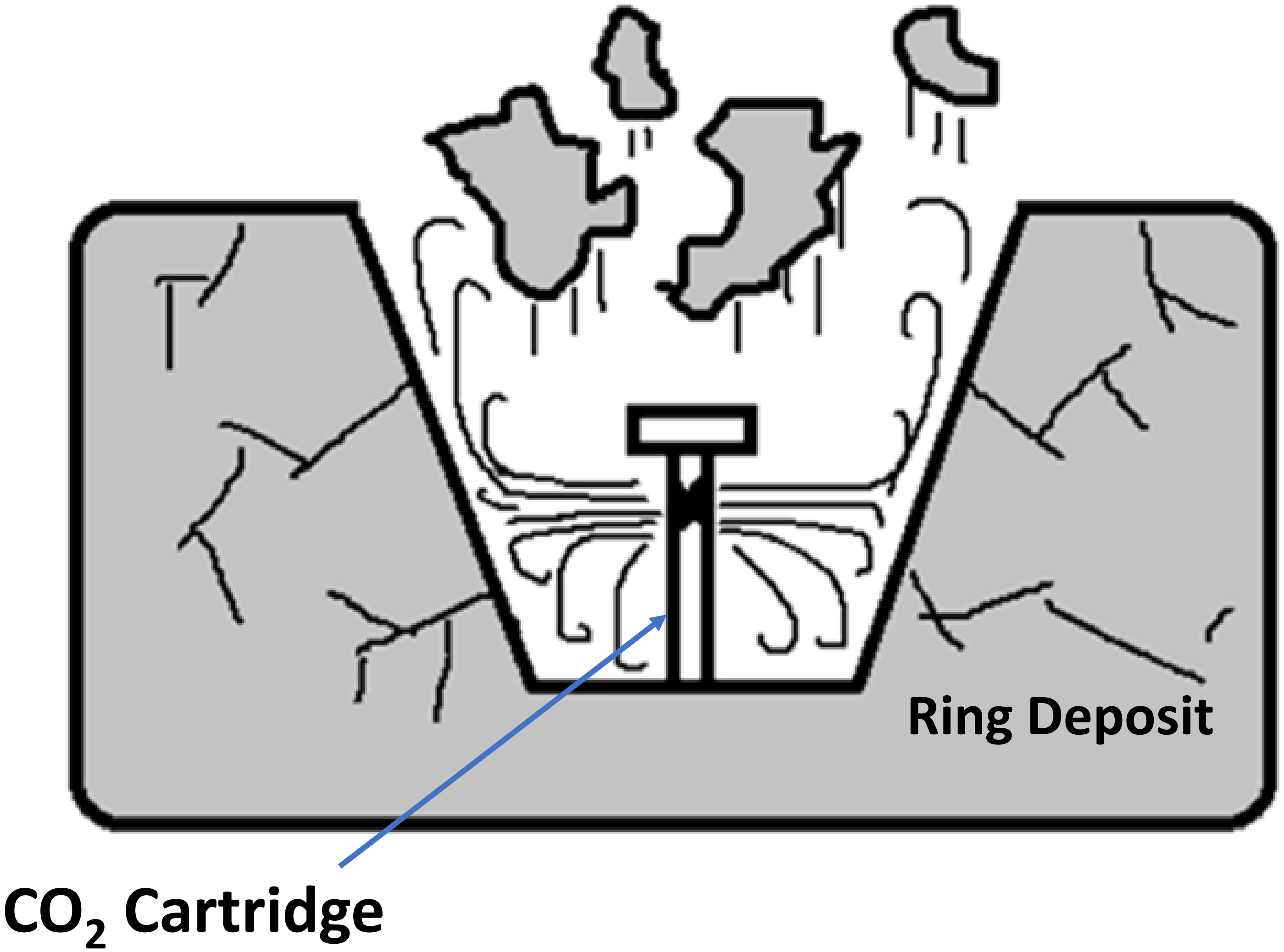
Lime kiln detention in January 2017

Ring at 23 meters

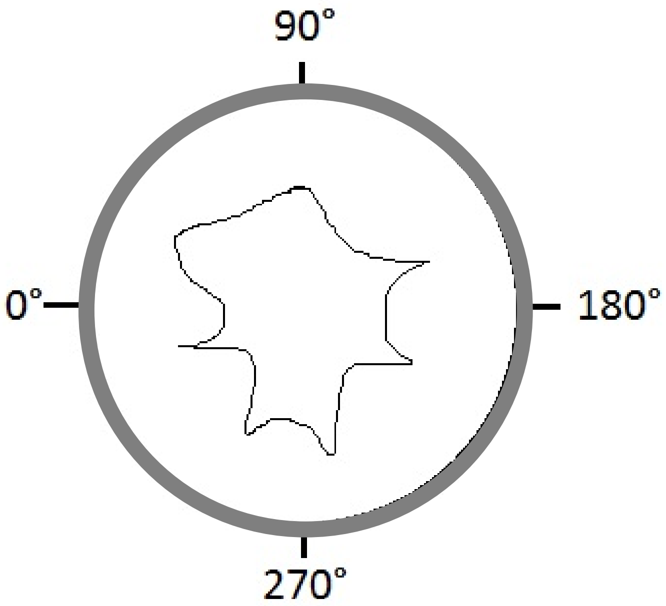
Ring at 43 meters

Lime kiln detention in January 2017

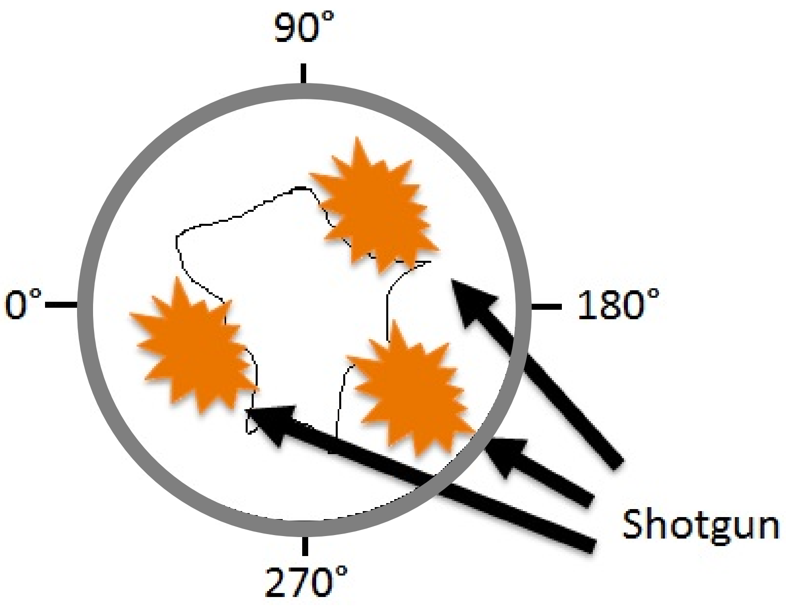
Lime kiln detention in January 2017



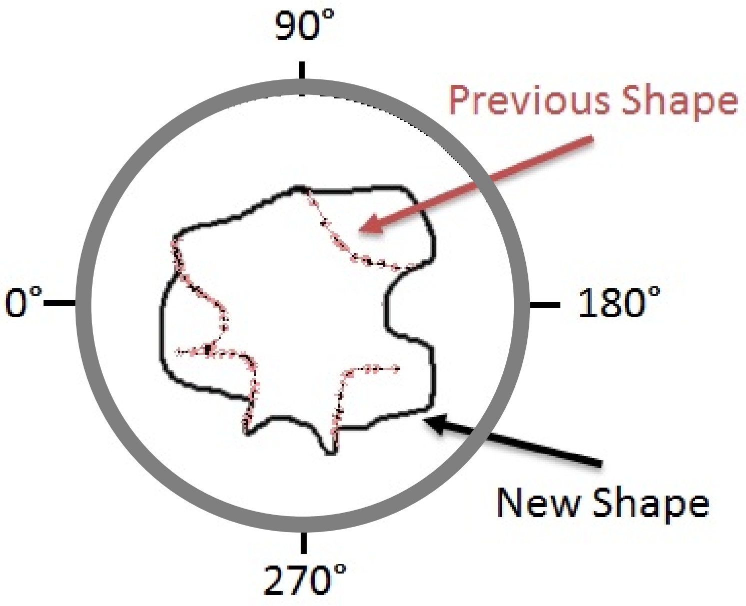
Historical mill strategy for ring removal with shotgun



Ring shape before shooting



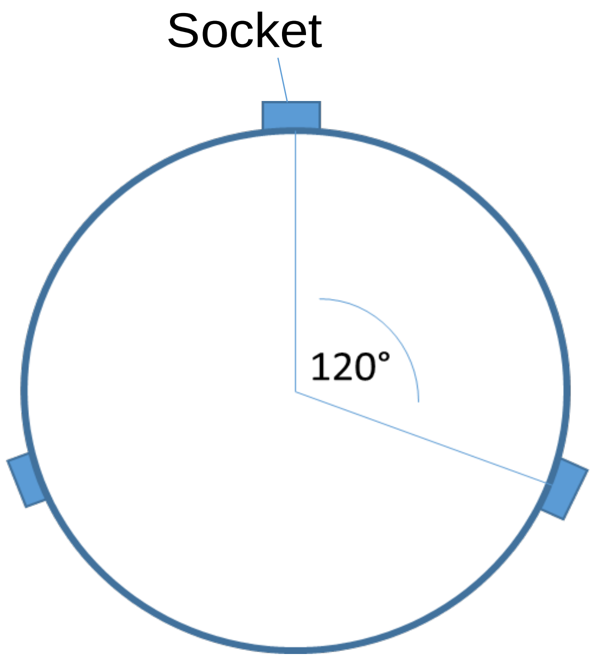
Shooting at different locations on ring



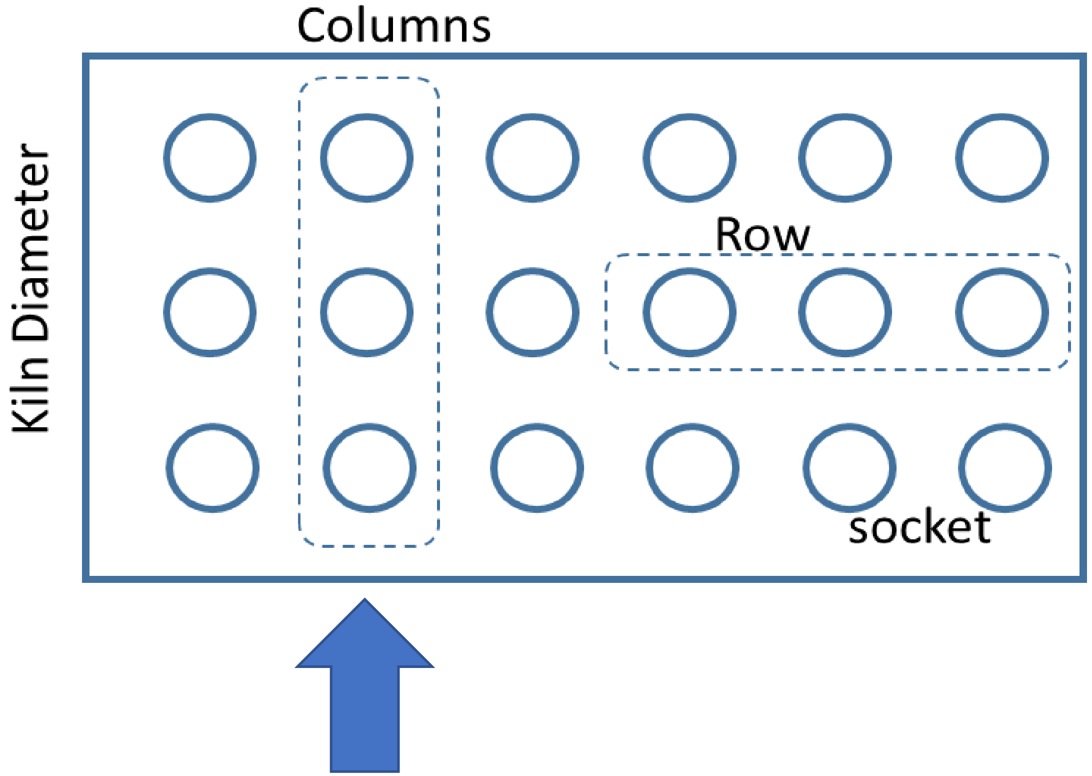
Ring shape after shooting

Ring didn’t fall

2016 ring removal strategy with CO_2 cartridge: Columns

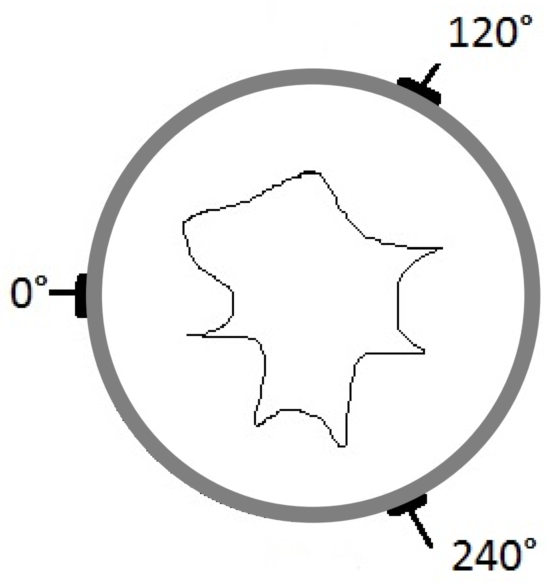


Socket locations

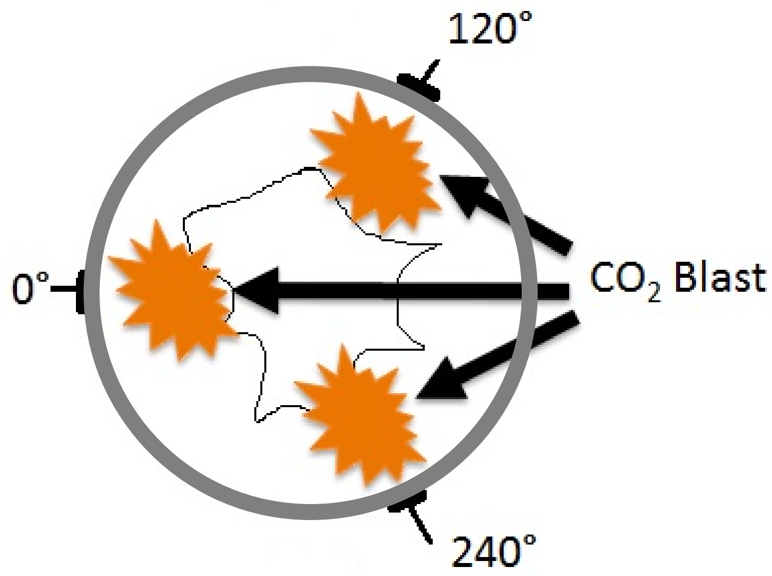


1st Approach

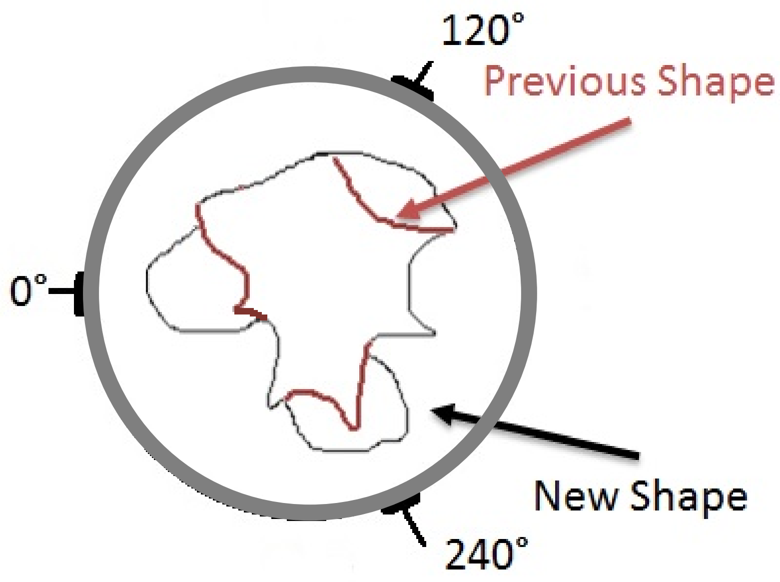
2016 ring removal strategy with CO_2 cartridge: Columns



Ring shape before CO_2 blasting



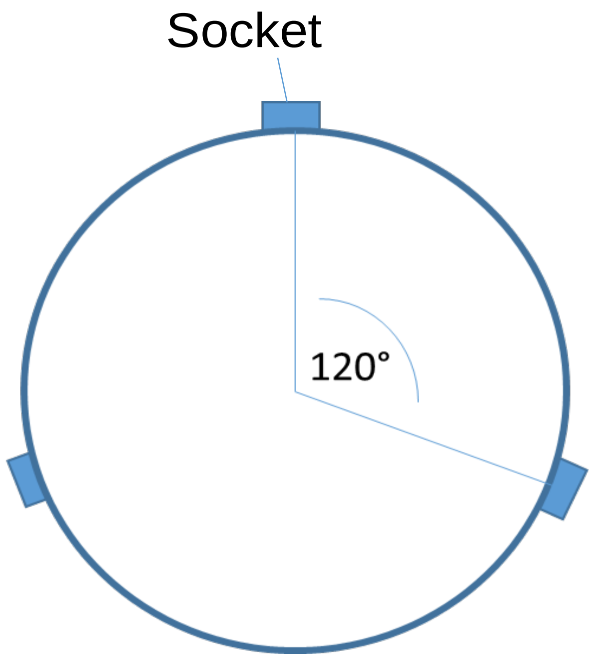
CO_2 blasting at different locations



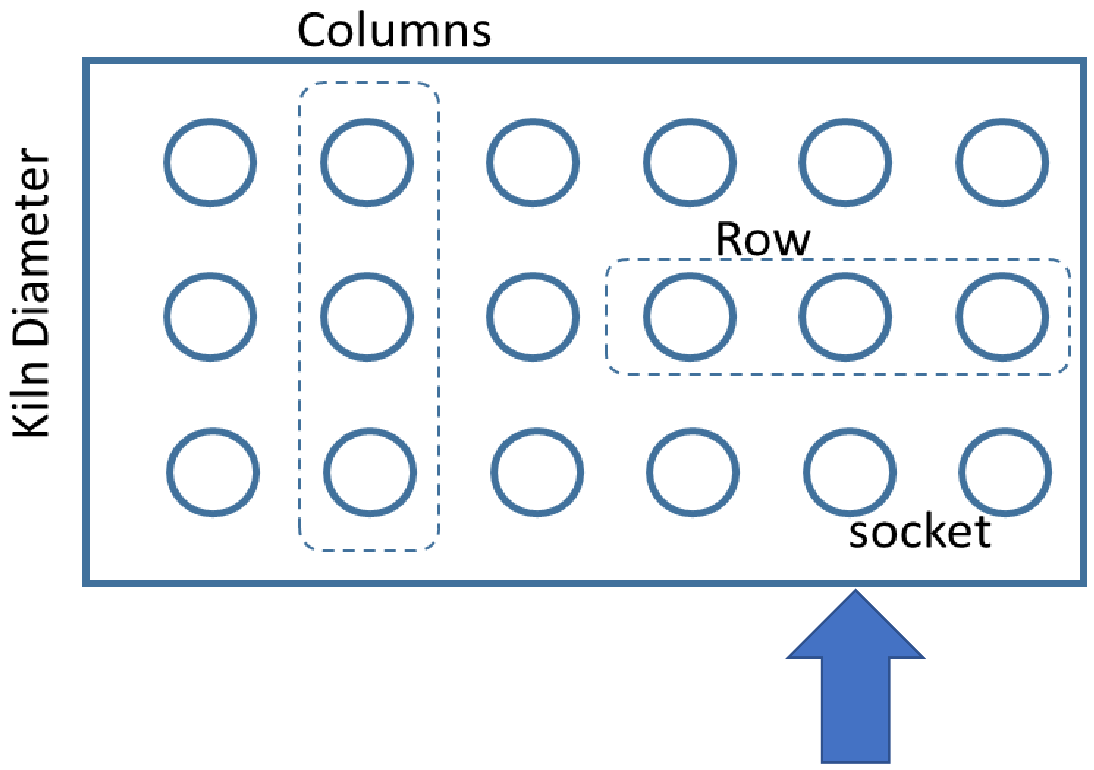
Ring shape after CO_2 blasting

Ring didn't fall

2018 ring removal strategy with CO_2 cartridge blast
Rows and Shotgun

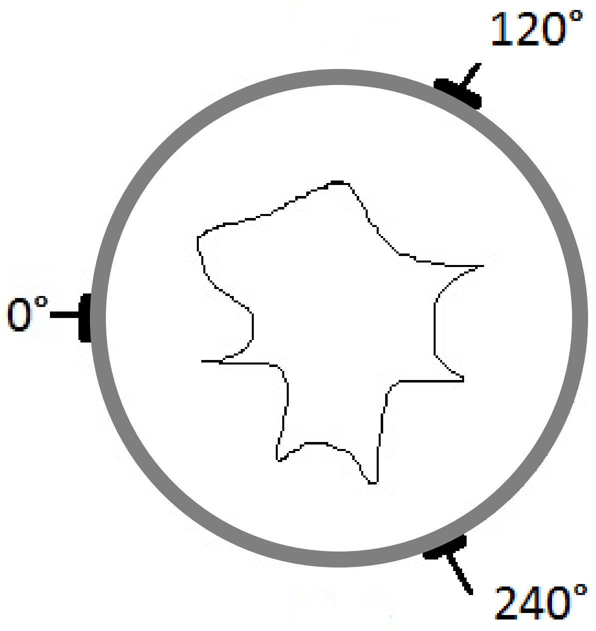


Socket locations

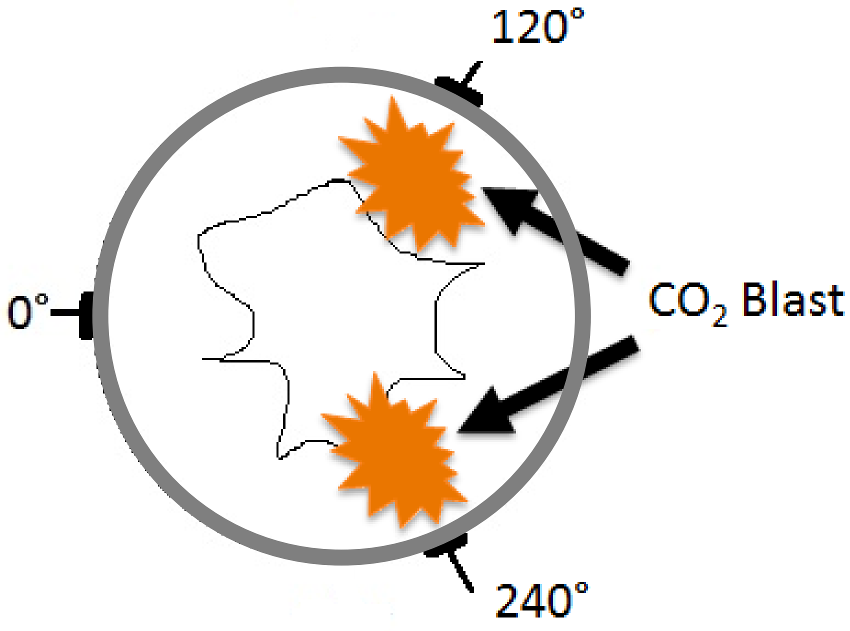


2nd Approach

2018 ring removal strategy with CO_2 cartridge blast: Rows and Shotgun

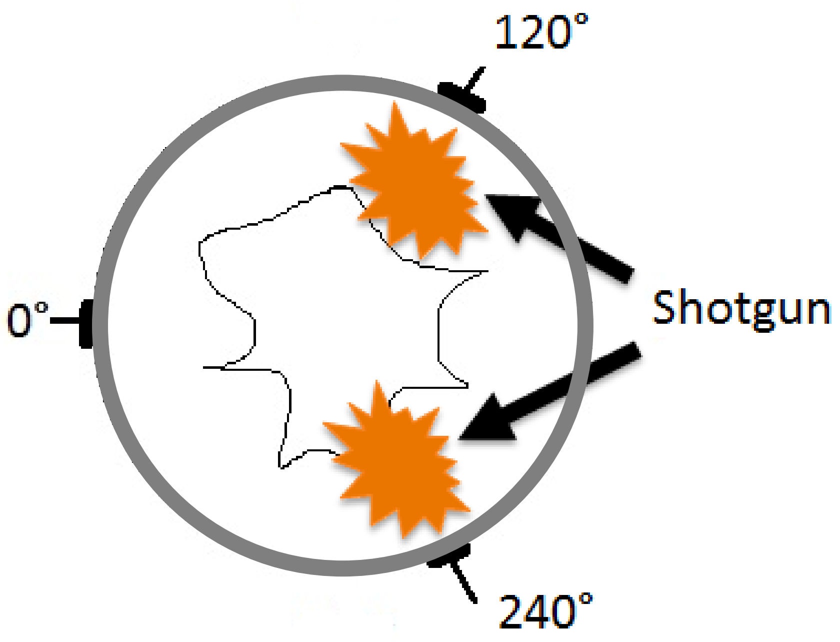


Ring shape before CO_2 blasting

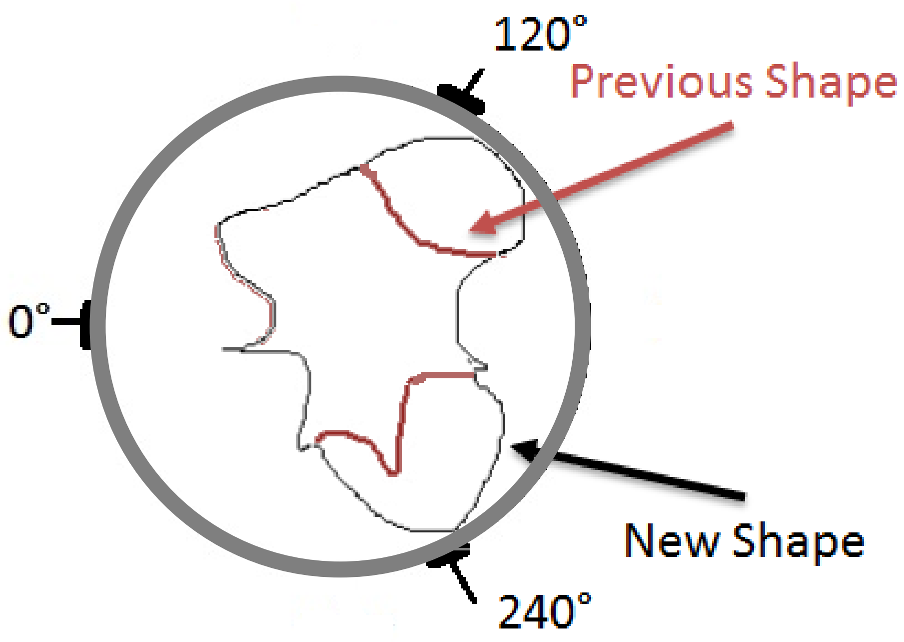


CO_2 blast at different locations

2018 ring removal strategy with CO_2 cartridge blast: Rows and Shotgun



Shooting with shotgun
1 week later



Final ring shape

Summary and Final Comments

- The CO_2 cartridge system worked well together with traditional shot gun in removing rings
- Since the adoption of our best ring removal strategy, the lime kiln has been able to run without shutdowns due to ringing
  - Ringing problems are still there, but manageable
- Finding an optimum strategy to maximize ring removal efficiency with minimum damage to refractory bricks was not an easy task
- It requires different approaches, knowledge, experience and team work