Combatting lime kiln ringing problems at the Arauco Constitución mill

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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 carbon dioxide (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 strategy was found to be the weekly blasting operation that alternated between the liquid CO_2 cartridge and the industrial shotgun, with the CO_2 cartridge inserted into the ring mass, 20 cm (8 in.) away from the refractory brick surface, and the shotgun aimed at rings at about 28 m (92 ft) from the kiln discharge end. With each blasting event removing considerably more rings than before, it takes a longer time for rings to rebuild, allowing the kiln to run continuously between annual maintenance shutdowns with only a few short (< 4 h) downtimes for ring removal. This substantially reduces the costs associated with ring removal and lime replacement during unscheduled shutdowns.

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

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 and upgraded in the 1990s, and it is presently producing 950 metric tons/day of unbleached radiata pine pulp. Woodchips are cooked in a rapid displacement heat (RDH) 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.

Of the six lime kilns at the company's five mills, three are having ringing problems. Of these three, the problem at the Constitución mill is the most severe. The kiln was a Polysius (Krupp Polysius; Beckum, Germany) unit built in 1976 and later modified by FLSmidth (FLSmidth & Co.; Copenhagen, Denmark) to the present dimensions of 3.2 m (10.5 ft) inside diameter (ID) 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 calcium oxide (CaO), the kiln has been operating at 30% over design capacity—producing 260 tons/day of lime—since the mill upgrade in the 1990s. 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 noncondensable gases (NCG) from batch digesters.

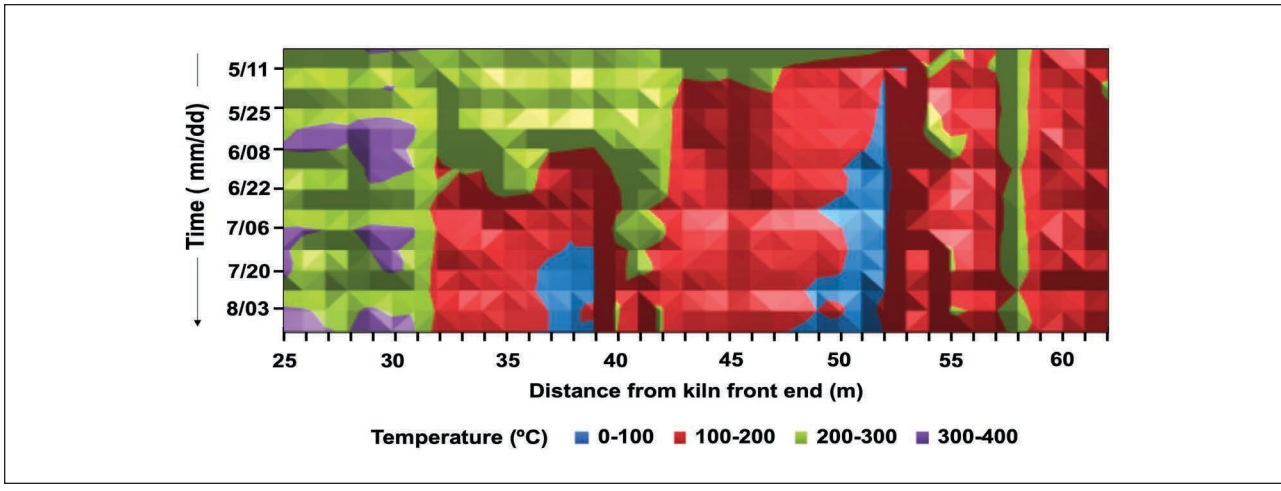
Rings consistently formed within 2 to 3 months after the annual maintenance shutdown and continued to grow until they became so large that the kiln needed to be stopped for ring removal (**Fig. 1**). On average, rings needed to be removed twice a year. One was during the mill's maintenance shutdown and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



1. Massive ring buildup observed during the annual maintenance kiln shutdown in February 2018.

The mill responded to the problems by:

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



2. Change in kiln shell temperatures with time leading to the ringing shutdown in 2015. Temperatures were measured using a manual laser thermal gun.

Chemical and thermal analyses of ring samples showed that they consisted mostly of calcium carbonate ($CaCO_3$), CaO, a large amount of sulfur (S), and a small amount of sodium (Na). The average S/Ca mass ratio of ring samples was 0.14, about 15 times larger than that of the product lime, while the Na/Ca mass ratio was 0.02, less than twice of that of the product lime. Such a high S and normal Na composition is typical for rings found in lime 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 led to rapid ring growth [3].

Numerous attempts have been made over the years to minimize ring formation by stabilizing the kiln/causticizing plant operations, but without much success. It was concluded that as long as NCG/SOG are still burned in the kiln, it is difficult to alleviate the ringing problem. 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) makeup to wear off the rings. While these methods helped control ring growth to some extent, they were unreliable and often ineffective. In mid-2016, the mill installed a new Cardox liquid CO_2 cartridge system (Cardox International Ltd.; Ashton-under-Lyne, England) on the kiln shell to help remove rings quickly and effectively.

This paper discusses the experience of using the liquid CO_2 cartridge system together with the industrial shotgun to remove rings at the Constitución mill. The discussion includes: i) the procedure for locating rings and monitoring their growth; ii) the installation of sockets on the kiln shell; iii) the procedure for drilling a hole through the socket to insert the CO_2 cartridge and detonate (blast) it; and iv) the blasting procedure and improvements.

LOCATING RINGS AND MONITORING RING GROWTH

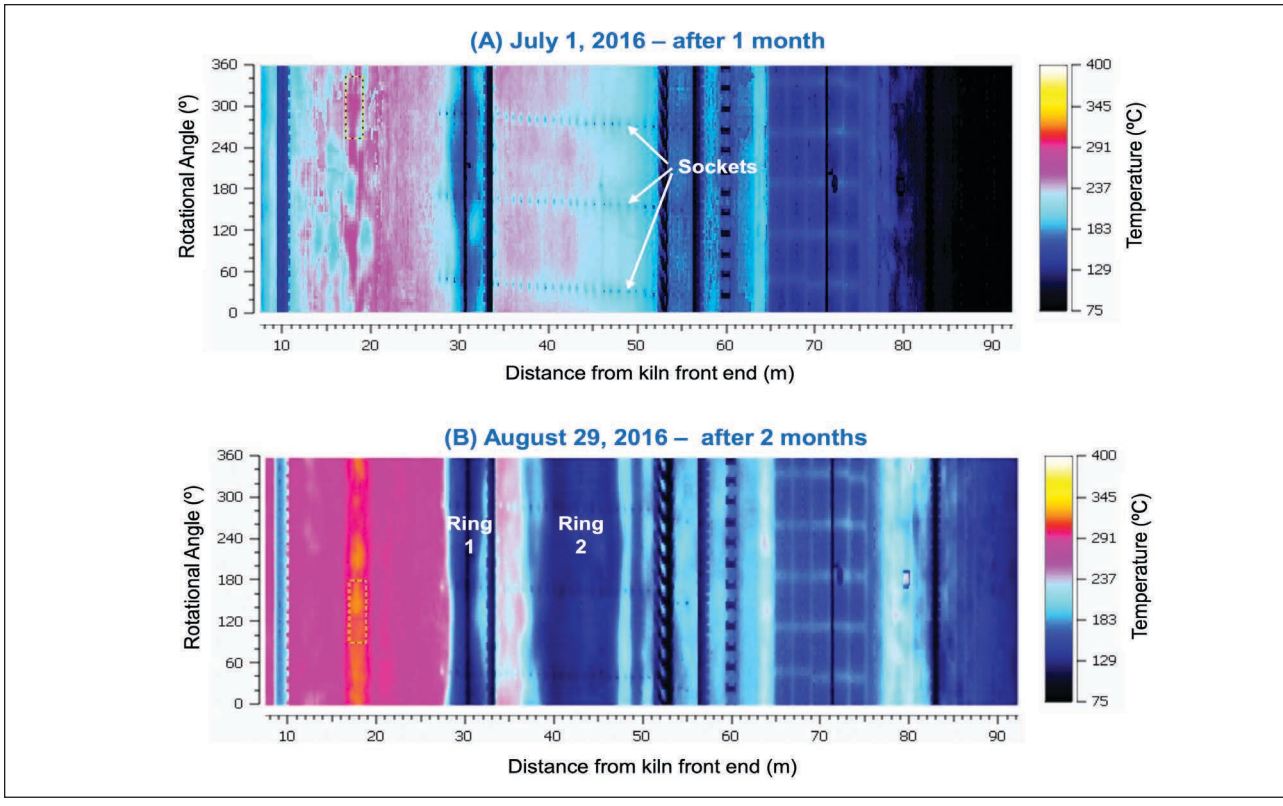
The increase in draft between the induced draft fan and the kiln hood at the discharge end and the increase in amperage (power) of the kiln rotation motor were constantly monitored and used as an indication of ring growth. These signals, however, could indicate only the presence of rings in the kiln, but not where they were.

Manual kiln shell temperature measurements

To locate rings, the kiln shell temperature 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, there was likely a ring formed in the kiln at that spot.

Figure 2 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 temperatures. Blue is where the shell surface temperature was below 100°C, red is where the temperature was between 100°C and 200°C, green is where the temperature was between 200°C and 300°C, and purple is where the temperature was the highest, 300°C–400°C.

As rings built thicker with time (arrow sign), 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°C–300°C (green) on May 11 to 100°C–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



3. Infrared images of kiln shell temperatures when there was: A) no or little ring buildup after one month; and B) massive ring buildup after about 2 months since the last kiln shutdown for ring removal.

was shut down for ring removal in August.

The change in kiln shell temperature profiles between May and August 2015 suggests that rings were initially formed at two locations (blue and red squares). 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.

Continuous kiln shell temperature measurements

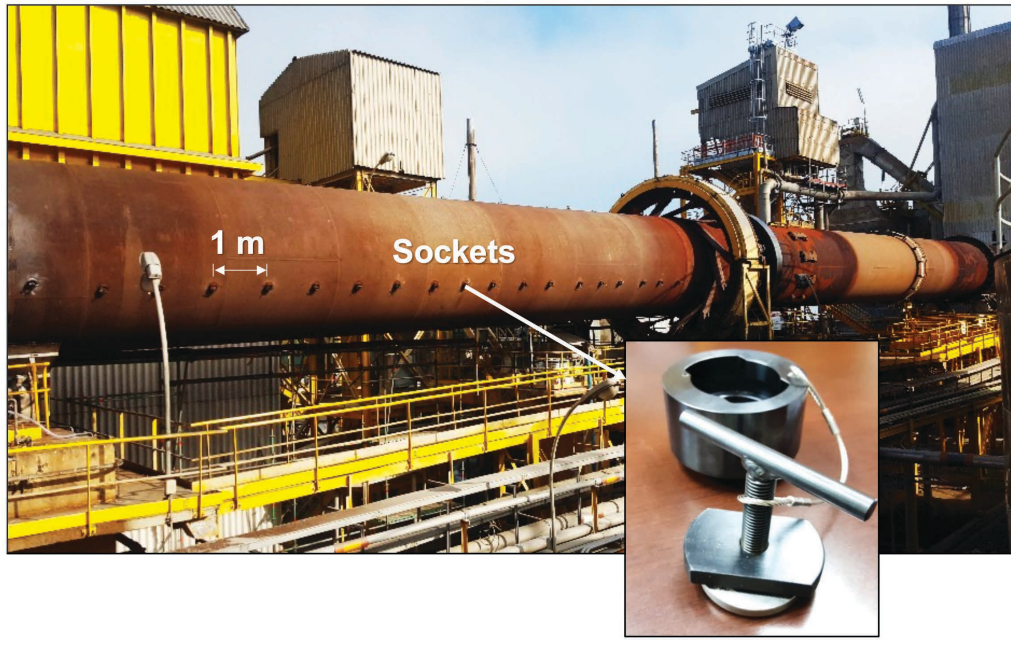
The mill installed an infrared imaging camera in 2016 to continuously scan the kiln shell temperatures and use the temperature data to determine where rings form and how they grow with time. The camera greatly improved the temperature measurements, providing online information on temperature distribution over the entire kiln shell surface, as opposed to only sporadic temperature readings obtained manually with the thermal gun. **Figure 3A** is an example of an instantaneous thermal image of the kiln shell taken on July 1, 2016, at 11:47 PM, one month after the kiln was in operation since its last shutdown for ring removal. The kiln shell temperature at the location between 30 and 50 m from the kiln front end (where rings usually formed) did not change much, implying there was no or little ring buildup inside.

At a constant burner flame (or flue gas) temperature inside the kiln, the shell temperature at a given location would decrease if there was a ring built up at that location. The infrared camera would consequently register a "cold" (lower shell surface temperature) area on the shell. Figure 3B 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 Fig. 3A (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.

INSTALLING SOCKETS ON THE KILN SHELL

Socket positions

Based on historical experience and the information obtained from the thermal laser gun, a total of 87 sockets were installed on the kiln shell 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 was 1 m. These three rows of sockets can be noted in Fig. 3A as small blue dots starting at 28 m and ending at 56 m from the kiln discharge end. **Figure 4** shows a closeup picture of a socket and its cap, and how sockets are aligned in a row on the kiln shell.



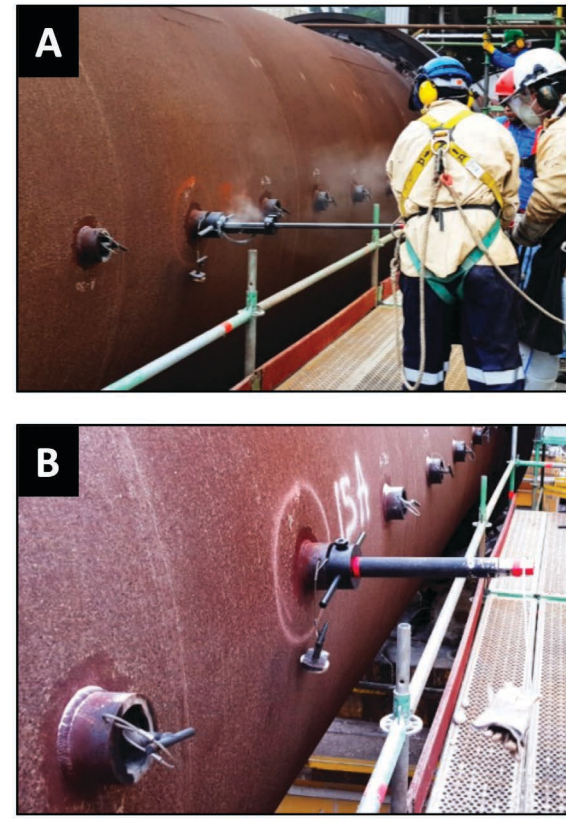
4. Sockets installed on the kiln shell during the 2016 annual maintenance kiln outage.

Choice of sockets to blast

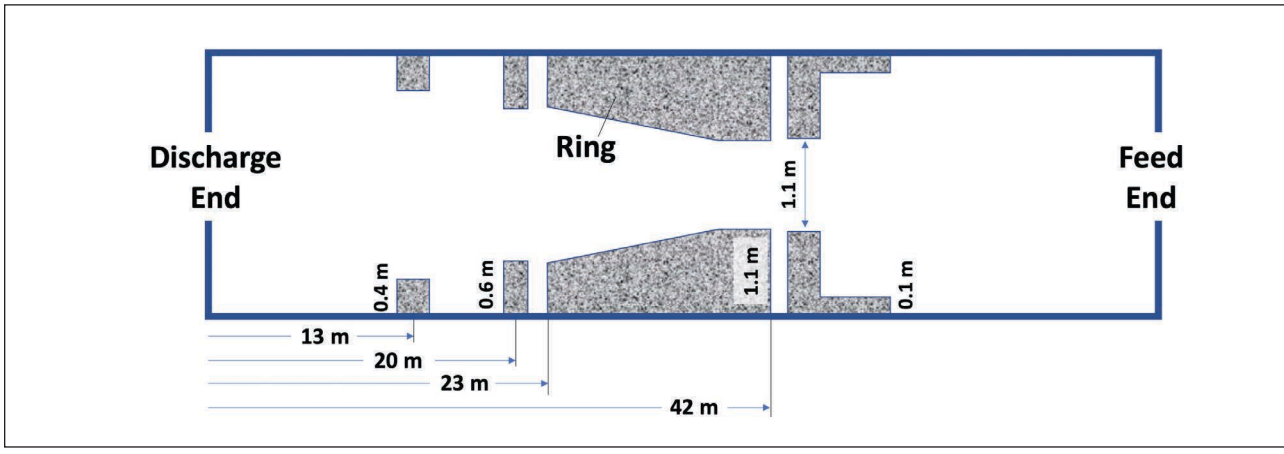
The question is which of the 87 sockets should be drilled through in order to insert the liquid CO_2 cartridge to do the blast? Typically, the flue gas temperature of the kiln rapidly increases, reaching a maximum value at about 18 m from the discharge end (near the tip of the burner flame) and then decreasing 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 Fig. 3, 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 computational fluid dynamics (CFD) modeling work and the kiln shell temperature profile, 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.

HOLE DRILLING 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. While the kiln is still hot, 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 ring buildup (**Fig. 5A**). A liquid CO_2 cartridge is inserted into the hole and securely mounted as shown in Fig. 5B. The cartridge is then connected to a remote trigger with electrical wires and detonated.



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



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

Note that due to its massive weight, the kiln may sag/bend downward in the middle if it does not rotate while it is still hot. To prevent kiln sagging, the mill put in place a blasting procedure in which the kiln must not stop rotating for more than 15 min. This means that if the drilling operation is not completed within that time frame, it must be suspended to allow the kiln to resume rotation for 5 min. This 15-min stop for drilling/5-min rotation for sagging prevention repeats until the liquid CO_2 cartridge can be securely fitted into the socket. Once this is done, it takes less than 2 min to detonate.

BLASTING PROCEDURE

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 remove rings efficiently and cost effectively. 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 build up 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 total time required for blasting depends greatly on the severity of the problem (i.e., the ring size) and the number and experience of the people involved. More massive rings, fewer people, and less experience understandably require a larger number of blasts and a longer time for complete removal. When the mill started adopting the practice, it took about 4 h to do only 2 blasts. With more experience accumulated over time, not only could the mill considerably speed up the blasting procedure, it could also more effectively remove rings. During the blasting event in early 2019, for instance, it took only 2 h for a crew of 3 people to complete 12 blasts. With each blasting event removing more rings than before, it takes longer for rings to build up again, and hence, allowing the kiln to run for a longer time between shutdowns due to ringing.

Detonating a liquid CO_2 cartridge is a dangerous operation and must be carried out with caution. Working with suppliers and consultants, the mill developed safety guidelines and procedures for blasting operation as follows:

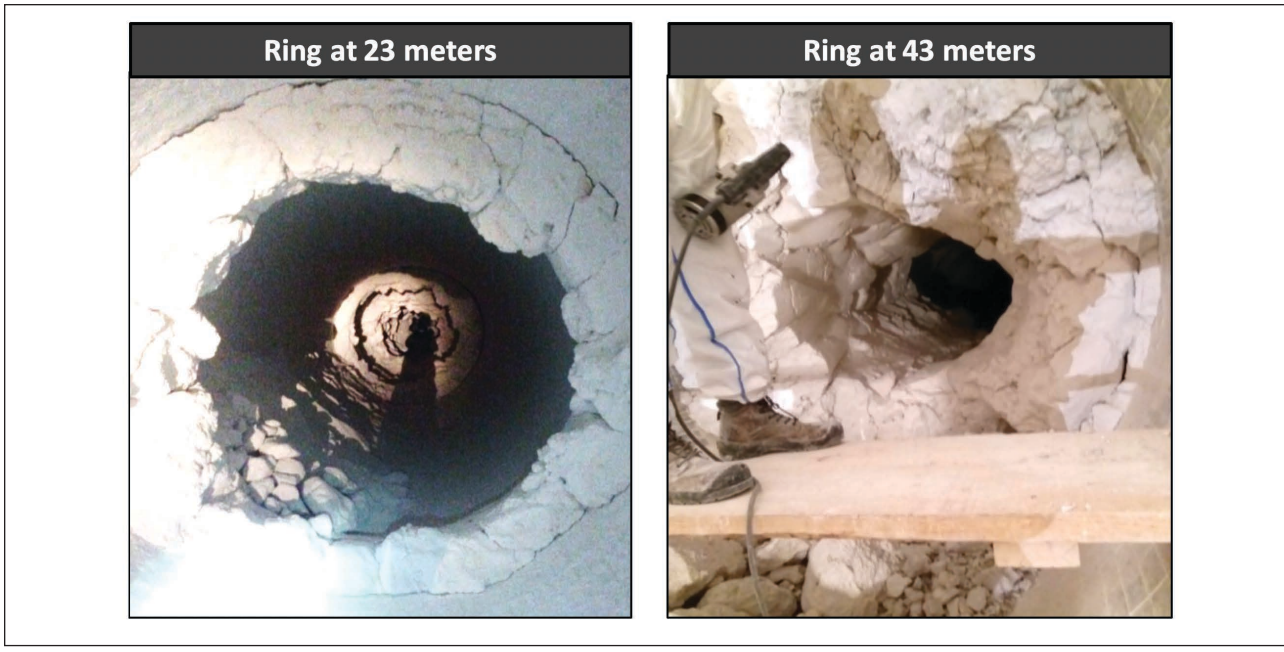
- The kiln superintendent in charge of the blasting operation is responsible for the safety of all workers involved and must go over all safety items on the checklist with his crew members before allowing them to drill holes through sockets to insert CO_2 cartridges.
- Areas around the sockets where blasts are to be carried out (i.e., access deck, scaffold, etc.) must be cleared. Barricades must be set up to prevent unauthorized personnel from entering the blasting area.
- A safety lock is installed on the CO_2 cartridge to prevent it from being blown back during the blast.

The initial experience at Constitución was 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, multiple blasts along with the use of the existing industrial shotgun were needed to accelerate the ring removal process. An improved blasting procedure was developed in-house that takes into account the ring thickness and location.

IMPROVED BLASTING PROCEDURE

While liquid CO_2 cartridges are relatively easy to work with, using them effectively to remove rings requires experience, good strategies, and proper procedures. Since ring thickness and hardness vary widely along the kiln, at any location, more than one blast may be needed to satisfactorily remove the rings.

Figure 6 schematically shows how the ring thickness changes with location observed during the January 2017 maintenance kiln outage after 8 months of operation. The buildup was not uniform along the kiln length, with little buildup in some sections and massive buildup in others. The first blast was carried out at the end of September 2016



7. Rings formed at 23 m and 43 m from the discharge end.



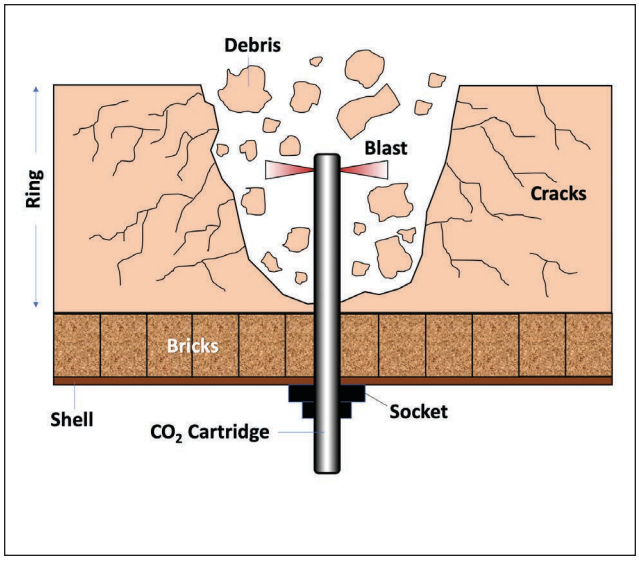
8. Holes formed in rings as a result of liquid CO_2 blasts.

and repeated every two weeks until the annual maintenance shutdown in January 2017 when the kiln was cleaned and inspected.

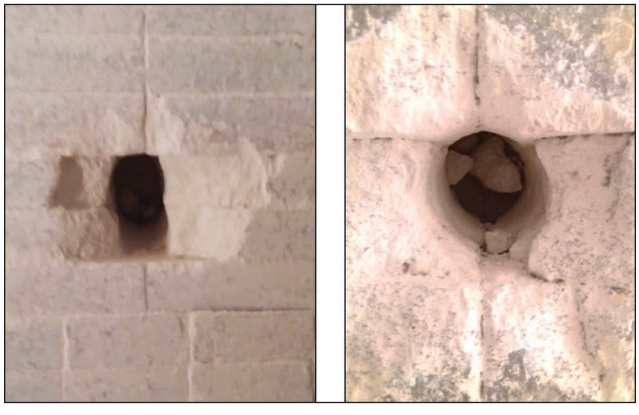
Figure 7 shows rings formed at 23 m and 43 m from the kiln discharge end. Despite repeated blasting, only holes were made in the rings (**Fig. 8**). The liquid CO_2 cartridge system was simply not effective enough to cause rings to fall and be removed.

Figure 9 schematically shows how holes might form in the ring as a result of blasting. As the liquid 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.

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 cartridge hole drilling (**Fig. 10**).



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



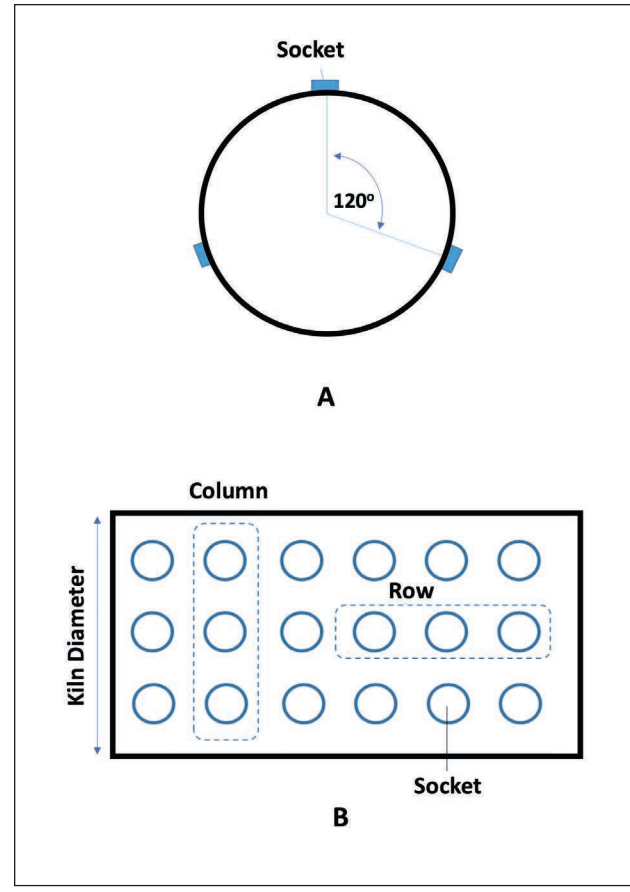
10. Brick damage incurred during cartridge hole drilling.

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 along or parallel to the kiln shell, while column drilling refers to drills that are made normal to the shell (**Fig. 11**).

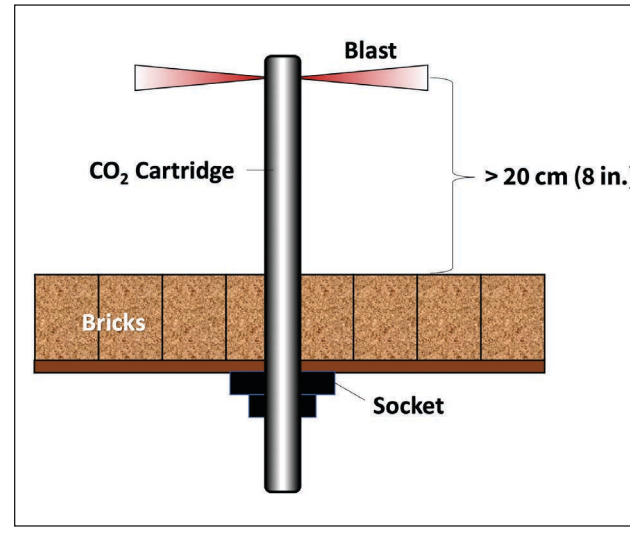
Numerous tests were performed to examine the optimum depth for placing the CO_2 cartridge into ring deposits. The results showed that the best depth to achieve the most efficient ring removal and the least brick damage was when the tip of the CO_2 cartridge was at least about 20 cm (92 ft) away from the brick surface (**Fig. 12**). After the blast, the drilled cartridge holes were completely filled with reburned lime and/or ring debris removed from the kiln.

An industrial shotgun was also used together with the liquid CO_2 cartridge system. However, it was only good for removing rings at a location closer than 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

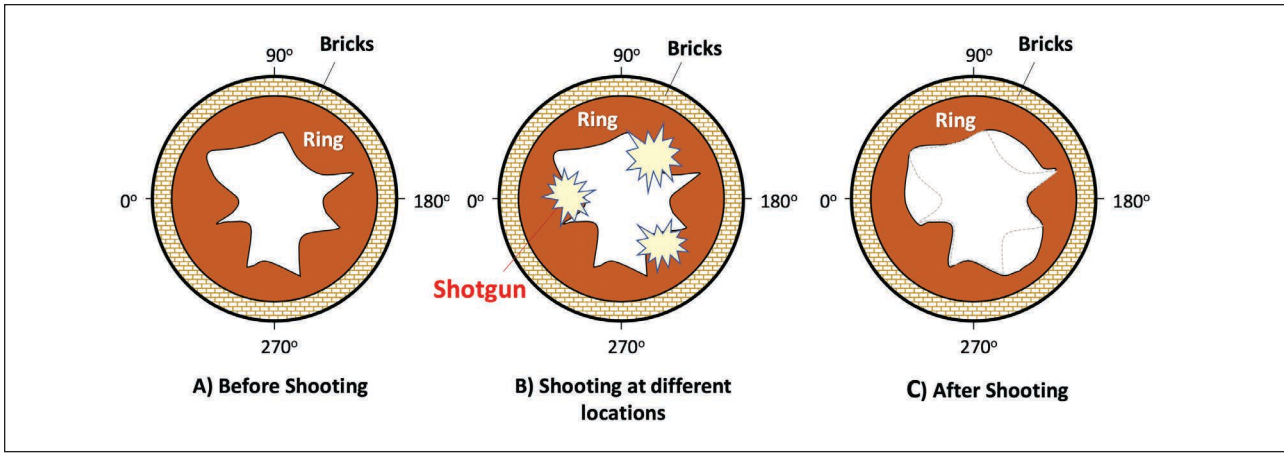


11. A) Cross section of the kiln through a socket plane; and B) distribution of sockets along the kiln length.

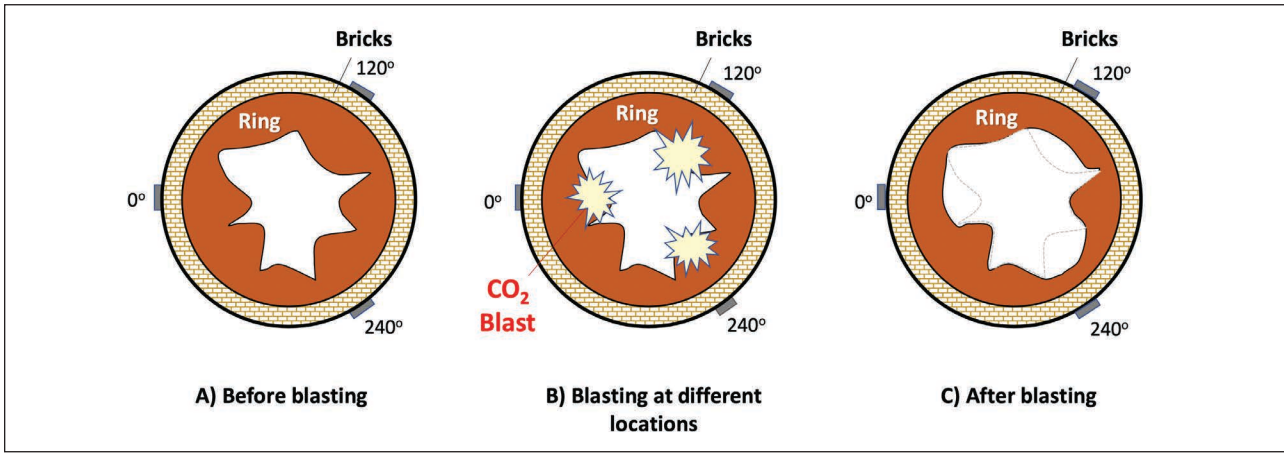


12. Optimum distance from the liquid CO_2 cartridge discharge to the brick surface.

at a time and as many as 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 **Fig. 13**. Understandably, it was more effective for controlling rings



13. Effectiveness of ring removal with shotgun prior to 2017: A) ring shape before shooting; B) shooting with shotgun at various locations; and C) ring shape after shooting.



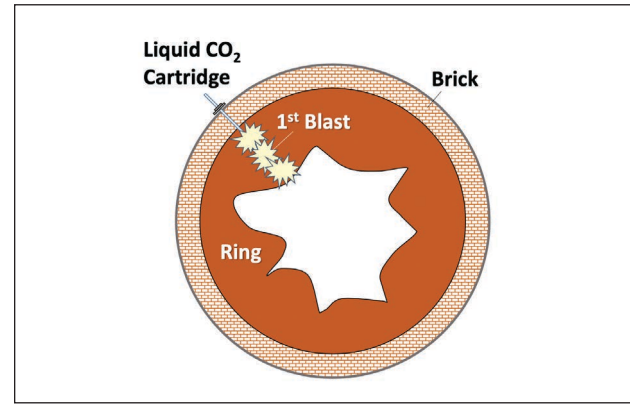
14. Effectiveness of ring removal with liquid CO_2 blasting through the sockets around the kiln circumference: A) ring shape before blasting; B) blasting at 0, 120°C, and 240°C positions; and C) ring shape after blasting.

that were closer to the discharge end than those located further back toward the feed end.

After the installation of the Cardox system and until the end of 2017, the liquid CO_2 blasting was through the sockets along the kiln circumference (column drilling in Fig. 11B), with a fixed depth of 20 cm from the refractory brick surface. As with the industrial shotgun, this blasting strategy was not able to effectively remove the ring, as shown in **Fig. 14**.

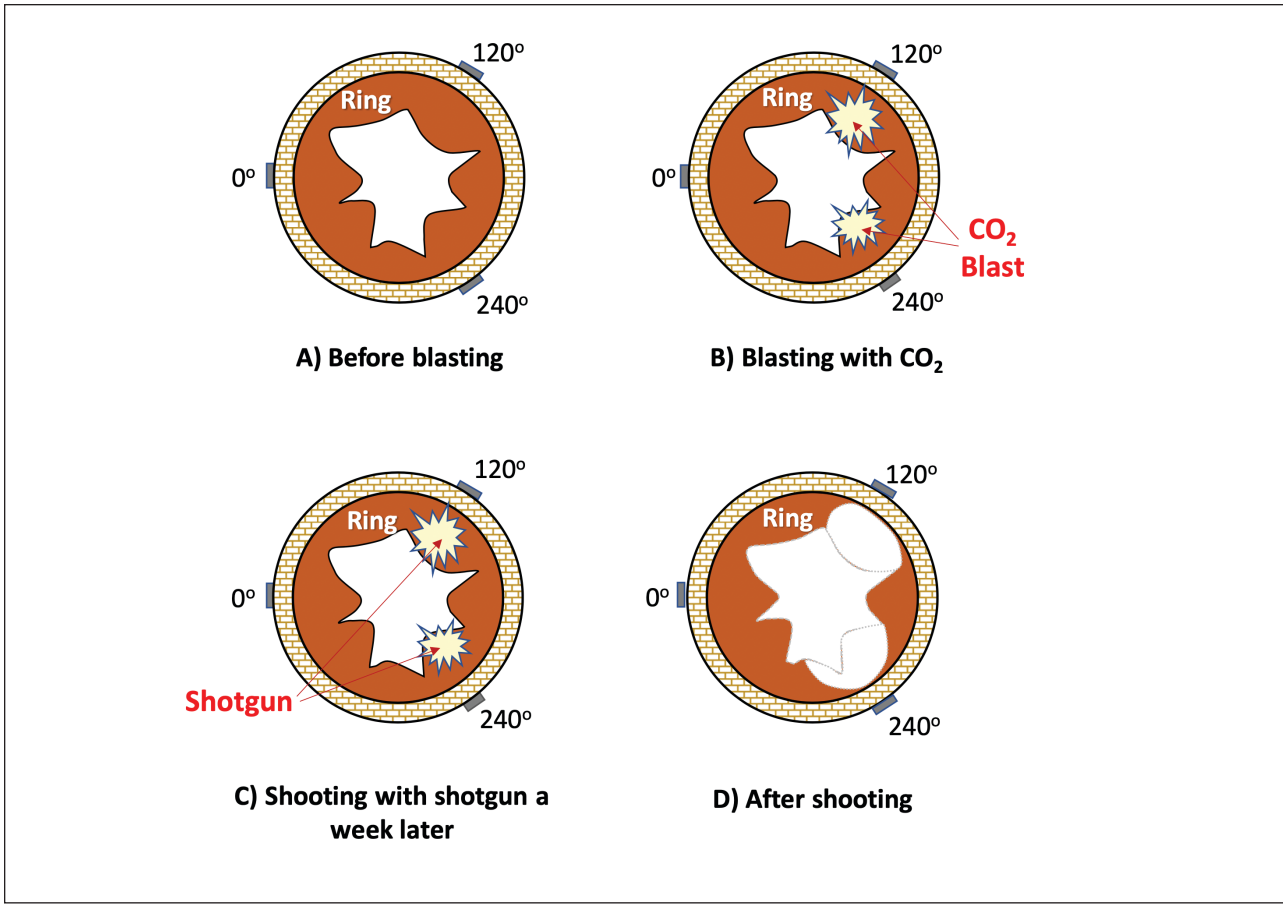
After trying various ways of blasting, the best strategy for the liquid CO_2 cartridge application was found to be blasting in the row direction, i.e., along the kiln axis (Fig. 11B). Furthermore, at any location, a minimum of 3 blasts at 2 different depths were needed for rings that were thicker than 50 cm (20 in.): one at about 1/3 and the other at about 2/3 of the ring thickness, as shown in **Fig. 15**. This was because one blast (the first one) was often insufficient to remove the buildup at that location.

The best strategy was found to be the weekly ring removal operation alternating between blasting with liquid



15. A minimum of 3 blasts are needed to remove a thick ring.

CO_2 cartridges and shooting with the industrial shotgun (**Fig. 16**). The liquid CO_2 cartridges should be placed in a row (along the kiln axial direction) and inserted into the ring mass 20 cm (7.8 in.) away from the refractory brick surface to minimize brick damage. With each blasting event



16. Best ring removal strategy by alternating weekly between blasting with liquid CO_2 cartridges and shooting with the industrial shotgun.

now removing more rings than before, it took longer for rings to build up to the same size again, thus allowing the kiln to run for a longer time between ringing shutdowns.

The improved strategy has been implemented since the beginning of 2018. It substantially reduces the costs associated with the large-scale ring removal operation and lime replacement during unscheduled shutdowns.

SUMMARY

The 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, along with installing a new Cardox liquid CO_2 cartridge system and using it together with the mill's 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 strategy was found to be the weekly ring removal operation alternated between blasting with liquid CO_2 cartridges and shooting with the industrial shotgun. Since each blasting event removes more rings than before, it takes a longer time for rings to rebuild. Thus, the improved blasting strategy enables the kiln to operate continuously between annual maintenance shutdowns with only a few short (< 4 h) downtimes for ring removal. This substantially reduces the costs associated with ring removal and lime replacement during unscheduled shutdowns.

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About this journal

ABOUT THE AUTHORS

Since the Arauco Constitución mill had invested substantially in lime kiln ring removal technology using liquid CO_2 cartridges, it needed to understand how the technology works so that it could make the best use of it. This study complements previous work performed mostly by equipment suppliers and consultants and describes the experience from a mill's (user's) point of view.

The most difficult aspect of this study was to identify the most suitable location to blast the ring. We addressed the problem through teamwork and good coordination between various departments involved (maintenance, operation, technology, and safety).

The study was much more challenging than we thought, but we managed to come up with an effective way to remove rings more safely and quickly without causing collateral damage to refractory bricks.

It was interesting to find that lime kiln rings are rather "stubborn." They do not collapse immediately after blasting but require a week to 10 days to fall out.

Other mills might use our experience to optimize their ring removal procedures and to increase their kiln availability. The next step is to continue to refine our ring removal practices as well as to stabilize the causticizing plant and lime kiln operations to minimize ring formation.



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