Ring removal in rotary kilns used by the pulp and paper industry

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ABSTRACT: Ring formation occurs in the rotary kilns used by the pulp and paper industry to regenerate the lime needed to produce white liquor. The main rings are: burning zone rings, mid-kiln rings, dust rings and/or mud balls, and mud rings. While the exact mechanisms of ring formation are not completely understood, frequent changes in the production rate and the mud solids, high soda content in the mud, and high levels of dust are believed to play a major role in ring formation.

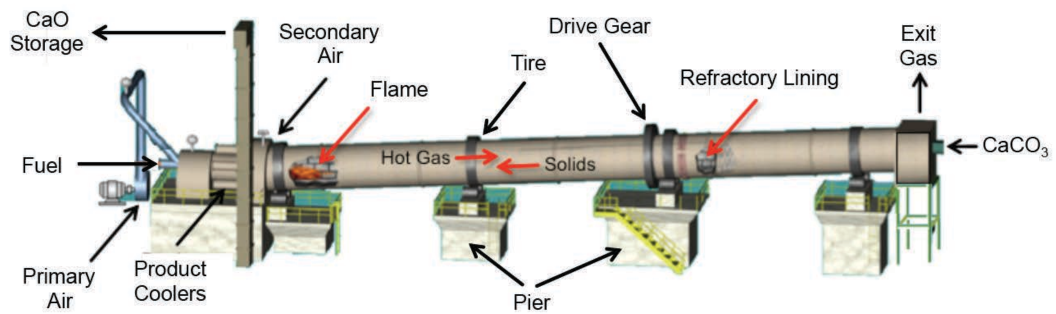
The presence of rings can restrict the movement of material through the kiln. If undetected, this can result in overheating of the refractory lining. In the worst case, the presence of rings can lead to unscheduled downtime to clean out the ring and replace damaged refractory bricks. Depending on the severity, the cost of repairs and lost production can be in excess of US$3 million for a single event.

Even if the root cause of ring formation is known, from a practical standpoint, it can be difficult to eliminate rings. In mills where ring formation is a recurring problem, mechanical ring removal systems should be considered. This paper describes the use of ring removal systems as a cost effective way to mitigate the problems associated with ring formation.

Application: Mills can use this information to determine if ring removal systems are appropriate for them. Also, the material can be used as a starting point to develop a project to select and install ring removal equipment.

Since the 1940s, the kraft process has been the dominant method used for producing wood pulp. To break the bonds that link cellulose to lignin, the wood chips are fed into a digester with a mixture of sodium hydroxide and sodium sulfide, referred to as white liquor. Following the pulping step, the cellulose fibers are separated and washed for further processing. The lignin and spent pulping chemicals, referred to as weak black liquor, are concentrated using a set of evaporators. The concentrated or strong black liquor is then fired in a recovery boiler to produce steam for use in the process and generating power. At the same time, the molten inorganic chemicals are recovered from the boiler and dissolved in water or weak wash. This solution is referred to as green liquor. The green liquor is then treated with lime (CaO) to regenerate white liquor for use in the digester. The recausticizing process that produces white liquor consumes lime and generates calcium carbonate ($CaCO_3$), referred to as lime mud, as a byproduct. A rotary kiln is then used to convert the calcium carbonate into lime for reuse in the process.

As seen in **Fig. 1**, the kiln is essentially a long rotating cylinder [1]. Lime mud from a drum or disc vacuum filter is fed into the upper or feed-end of the kiln. Due to its rotation, the mud travels down the length of the kiln where it is exposed to and heated by hot gases traveling in the opposite direction generated by a burner located at the lower or discharge-end of the unit.



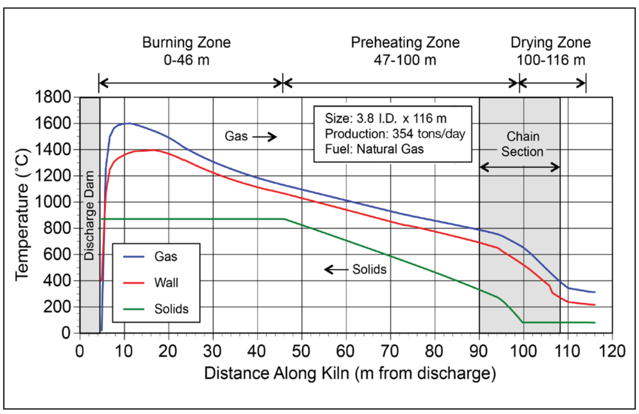
1. Schematic of a rotary kiln used to burn calcium carbonate ($CaCO_3$) to produce lime (CaO) in a kraft pulp mill, with cutaway sections showing the flame and the refractory lining.

The kiln may be divided into the following three zones.

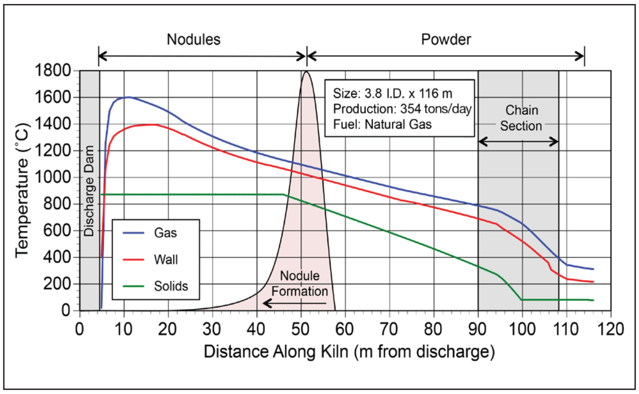
1. *Drying Zone*: The mud is dried in this zone. The temperatures of the solids are nearly constant at a value around 80°C (175°F). Metallic chains are hung in this zone to provide extra surface area to improve the drying process. This is normally the shortest zone in the kiln.
2. *Preheating Zone*: The dry material is heated in this zone from 80°C to 871°C (175°F to 1600°F). Nodule formation starts here.
3. *Burning Zone*: The calcination (thermal decomposition) of calcium carbonate to form lime occurs in this zone. The temperatures of the solids are fairly constant at a value around 870°C (1598°F).

The temperature profiles for the gas, inner surface of the refractory lining, and the solids for a 3.8 m inner diameter (I.D.) x 116 m long kiln (12.5 ft x 380 ft) are shown in **Fig. 2** with the three zones marked. Note that the zones correspond well with the temperature profile of the solids. The length and relative position of each zone is a function of several factors, including kiln geometry, type of product coolers, flame shape and position, and fuel properties.

Along with calcination, the kiln also acts to agglomerate the particles of mud. Around 800°C (1472°F), the sodium and potassium salts react with the nonprocess elements in the mud to form liquids, with a portion of the alkalis being volatized in the kiln atmosphere. Once formed, the liquids wet the particles of mud. To reduce the surface free energy, the particles quickly grow into the nuclei or seeds responsible for nodule formation. In response to the tumbling action of the bed, the nuclei collide with one another with many of these collisions, forming capillary necks leading to coalescence. During this stage, the growth rate of the nodules reaches a maximum. Eventually, as the diameter of the nodules increases, the growth rate slows as the separating torque between the nodules increases.



2. Predicted gas, inner refractory wall, and solids temperature profiles showing the major zones for a 3.8 m inner diameter (I.D.) × 116 m long kiln. These zones correspond well with the temperature profile of the solids. Chains are hung in the back of the kiln to provide additional surface area to assist in drying the mud.



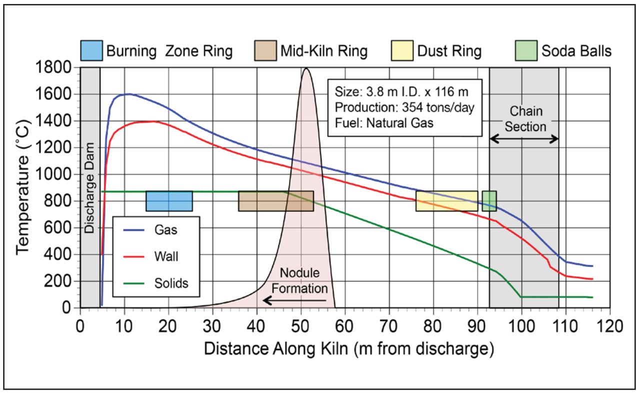
3. Just before the onset of calcination, around 800°C, the sodium and potassium salts react with the nonprocess elements in the mud to form liquids that act as a binder for nodule formation. The area shaded in red shows the region where nodules are formed.

The average diameters of the nodules range from 5–50 mm (0.2–2 in.). The region where nodules are formed in the kiln is marked in **Fig. 3**.

RING FORMATION

In addition to the particles of mud colliding with one another to form nodules, they can also collide with the refractory wall. In some cases, the particles stick to the wall. Over time, the accumulation of these particles forms a ring [2,3,4]. Initially, the ring is soft and porous. As it grows, the interior of the ring cools and if the partial pressure of carbon dioxide (CO_2) in the gas contacting the ring is high enough, re-carbonization of the lime inside the ring will occur when the interior temperatures drop below 800°C. The re-carbonization reaction results in sintering that increases the strength of the ring, which prevents it from falling out. Due to their location, these rings are commonly referred to as "mid-kiln" or "100-foot" rings. Typically, they are elongated, being some 10–15 m (32–50 ft) in length starting 9-10 kiln diameters from the discharge end of the kiln. They have a layered structure that follows the curvature of the kiln shell. All lime sludge kilns have some degree of mid-kiln ringing.

In a manner similar to that previously mentioned, moving toward the back of the kiln, at the location where the gas temperatures reach 800°C, the sodium and potassium salts in dust particles being carried by the gas form liquids, which causes them to stick to the walls, forming rings. Also, at the location where the temperature of the refractory drops below 800°C, a portion of the alkalis in the gas that volatized in the hotter regions of the kiln will condense on the wall. Local accumulations of the condensed liquid wet the dust particles on the wall, further contributing to the formation of rings [5]. Because the solids in the bed are still very fine at these locations, they do not create sufficient abrasive action to remove the



4. Location of burning zone ring, mid-kiln ring, dust ring, and soda balls in the kiln. This data should be viewed as typical for a kiln with satellite coolers fired with natural gas. The temperature profiles and exact location of these rings is impacted by kiln geometry, fuel type, and operating conditions.

ring. Referred to as "dust rings," they are fairly soft and normally fall out under their own weight. As is the case for mid-kiln rings, re-carbonization can strengthen these rings, preventing them from falling out. High gas velocities and poor nodule formation leading to high levels of dust play a major role in the formation of these rings. They are typically located between the drive gear and the hot end of the chain section.

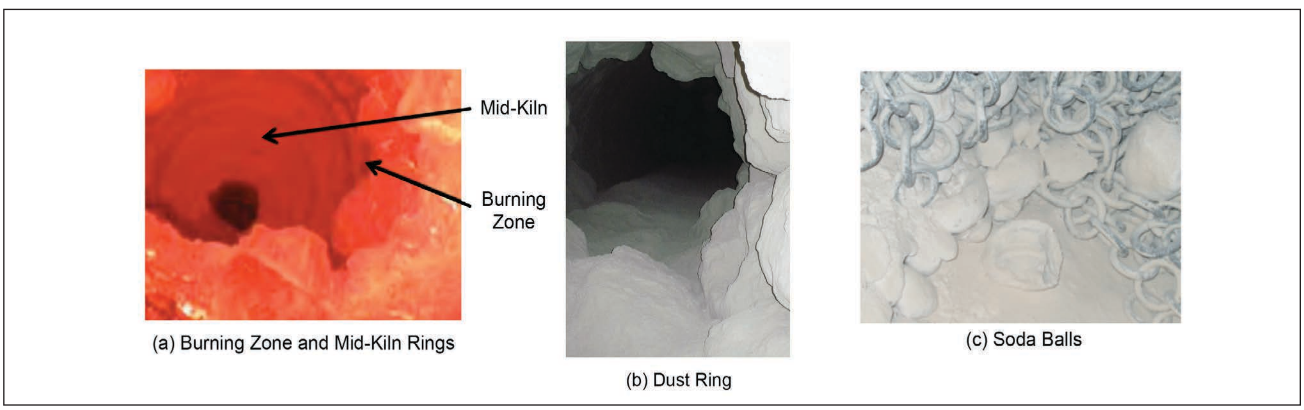
Along with rings, deposits can form on the chains in cases where the surface temperatures of the chains or the gas entering the chain section are around 800°C. Again, the liquids formed by the alkalis melting in the dust and the condensation of alkalis in the gas on the surface of the chains cause the particles of dust to stick to the chain. When this happens, "soda balls" can form on the last few rows of chain hung on the hot end of the chain section. The tumbling action of the chain is sufficient to stop the formation of these balls further inside the chain section. The weight of the balls hanging on the chain can cause them to fail. The use of low-cost natural gas, combined with the need to significantly increase production over the original kiln capacity rating, has increased the gas temperatures in the back of kilns. Special care must be taken to correctly size the chain system to minimize the formation of soda balls and buildups at the hot end of the chain section.

In addition to the previously mentioned scenarios, rings can form in the burning zone when there is an excess of sulfur over alkali in the kiln atmosphere [6]. At the temperatures in the burning zone, the SO_2 and SO_3 will react with the deposits of dust on the wall to form calcium silicosulphate ($Ca_5(SiO_4)_2SO_4$). The formation of calcium silicosulphate hardens the deposits, preventing them from falling out. In most kilns, the excess sulfur is introduced into the kiln with the fuel (e.g., sulfur-rich oil or pet coke), but these rings are also observed when firing sulfur-free fuels (e.g., natural gas). In the latter case, the excess sulfur in the kiln atmosphere results from low levels of alkalis in the mud. Reducing conditions in the kiln atmosphere are also reported to contribute to ring formation. The position and shape of the flame also play a role in forming these rings. Referred to as "burning zone" rings, they are very hard and are typically found just past the end of the visible flame.

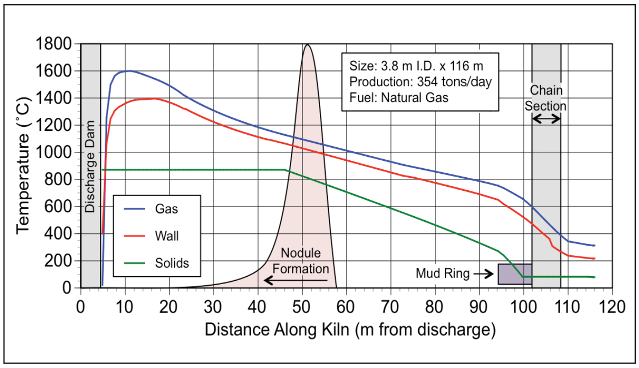
The locations of the various rings in the kiln are shown in **Fig. 4**. These locations should be viewed as being typical for a kiln equipped with satellite coolers firing natural gas. The temperature profiles and exact locations of these rings are impacted by kiln geometry, fuel type, and operating conditions. Not all of these rings will be seen at the same time. Photos of each type of ring are presented in **Fig. 5**.

In addition to high temperature rings, wet mud exiting the chain section can also form a ring. When the moisture content of the solids leaving the chain section is in excess of 15%, the mud is sticky and easily adheres to the refractory lining and will quickly build a ring. Referred to as "mud rings," these rings normally do not harden and eventually fall out. Under the right conditions, CO_2 in the gas phase can react with calcium hydroxide ($Ca(OH)_2$) in the mud to form $CaCO_3$. The formation of $CaCO_3$ acts to strengthen these rings, preventing them from falling out. These rings always form adjacent to the chain section [7].

The location of mud rings is shown in **Fig. 6**. Over the years, the requirements to increase filter surface area to meet



5. Photos showing (a) burning zone and mid-kiln rings, (b) dust ring, and (c) soda balls. These should be viewed as typical for kilns in the pulp and paper industry. Their appearance may vary. Mid-kiln rings have a layered structure. No layered structures are seen in the burning zone or dust rings.



6. Location of mud rings in the kiln. These rings may form when the moisture content of the mud existing in the chain system is greater than 15%. These rings are soft and normally fall out.

environmental regulations, along with other improvements in dewatering and washing technologies, have resulted in increased mud solids. Also, the use of continuous cleaning systems has greatly reduced the need for sheet drops to clean the filter cloth, thereby keeping the water content of the mud at a constant level. The combination of these factors has dramatically reduced the issues with mud rings.

MINIMIZING RING FORMATION BY IMPROVED OPERATIONS

Ring formation can be reduced by:

- Stabilizing the kiln operations:
  - Minimize changes to the feed rate of the mud
  - Reduce variations in the water content of the mud
  - Properly wash the mud to reduce levels of alkali and sulfur
  - Tightly control the level of excess air
  - Maintain residual carbonate at target values
  - Minimize shift-to-shift changes in operating procedures
- Reducing the dust loss:
  - Lower gas velocities in the kiln
  - Proper maintenance of coolers and the kiln discharge to minimize comminution of solid material
  - Minimize particles in the feed that are less than 20µ (i.e., if possible discard a portion of dust returned from the precipitator)
- Optimizing the burner design:
  - Keep the heat release close to the kiln discharge (i.e., short-to-medium length flame)
  - Maintain an oxidizing environment in the burning zone
  - Adjust the burner to prevent the flame from continuously washing the wall
- Routinely discarding a portion of the mud to control the buildup of nonprocess elements.
- Optimizing the chain system:
  - Hang the proper amount of chain
  - Replace worn chain on a regular basis

MONITORING RING FORMATION

The following changes in operating conditions are caused by the presence of rings:

- Increased pressure drop through the kiln
- Increases in induced draft (ID) fan speed or damper position over standard speeds or position for routine production and firing rates
- Decreasing exit gas temperature without a change in the mud feed rate or moisture content
- Increasing kiln drive motor amperage indicative of increased mud volume in the kiln
- Increase in the firing end temperature accompanied by decreases in the exit gas temperature
- Decreases in exit gas oxygen (O_2) coupled with ID fan speed increases or damper position

In addition to monitoring changes in operating conditions, handheld and/or continuous optical pyrometers should be used to monitor the kiln shell temperatures. A localized decrease in shell temperature accompanies rings. Routine internal visual observation of rings with the mud feed stopped, the burner off, and the kiln drive briefly stopped should be performed. Once the presence of a ring is confirmed, it should be closely monitored.

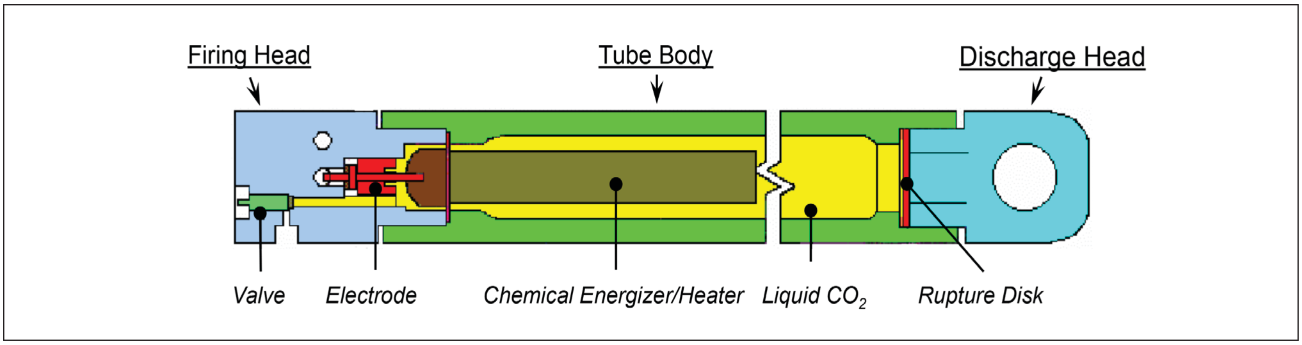
TECHNIQUES USED TO PHYSICALLY DISLODGE RINGS

There are no “silver bullets” to eliminate ring formation. Making progress on reducing ring formation requires a continuous effort to improve kiln operations over an extended period of time. Unfortunately, dealing with rings can be a frustrating experience for mill personnel. Rings can very quickly assume massive proportions, restricting the flow of gas and solids in the kiln. In some cases, the kiln must be shut down to remove rings. In the worst case, if not detected, the drop in throughput resulting from the blockage of solids caused by a ring can lead to overheating and failure of the refractory lining in the burning zone. The cost for shutting down a kiln to remove a ring and make repairs to the refractory lining can be in excess of US$3 million.

While not directly focused on solving the root cause of ring formation, once a ring begins to impact operations, the following options can be used in an effort to physically dislodge it from the kiln. In this way, the risk of burning out the refractory lining, damaging the shell, and taking unscheduled downtime are greatly reduced.

- Shooting with shotgun
- Thermal induced stress cycling
- CO_2 gas cartridge (cardox)

Industrial 8 gauge shotguns are used to remove rings in the burning zone. These guns shoot 85 g (3 oz) slugs down the kiln in an effort to cut a keyway through the ring. The ring is normally shot first in the eleven o’clock or one o’clock position. In many cases, rotating the kiln once or twice after a



7. Schematic of gas cartridge consisting of a high-strength steel tube filled with liquid carbon dioxide (CO_2). A chemical energizer is inserted in to the firing head with a rupture disk on the discharge end of the tube.

8. Photograph of 50 mm outer diameter (O.D.) x 1.25 m long CO_2 gas cartridge showing the firing and discharge heads. A 2-hole discharge head is shown here. A four-hole discharge is also available. Both the two- and four-hole designs work well to dislodge kiln rings.

keyway has opened will cause the remainder of the ring to drop out. The consumption of ammunition significantly increases when shooting at rings more than 30 m (98 ft) uphill from the discharge. Shotguns are ineffective in removing rings that are not clearly visible from the firing end of the kiln. Also, the approach does not work well if the rings are much more than 1 m (3.3 ft) in length.

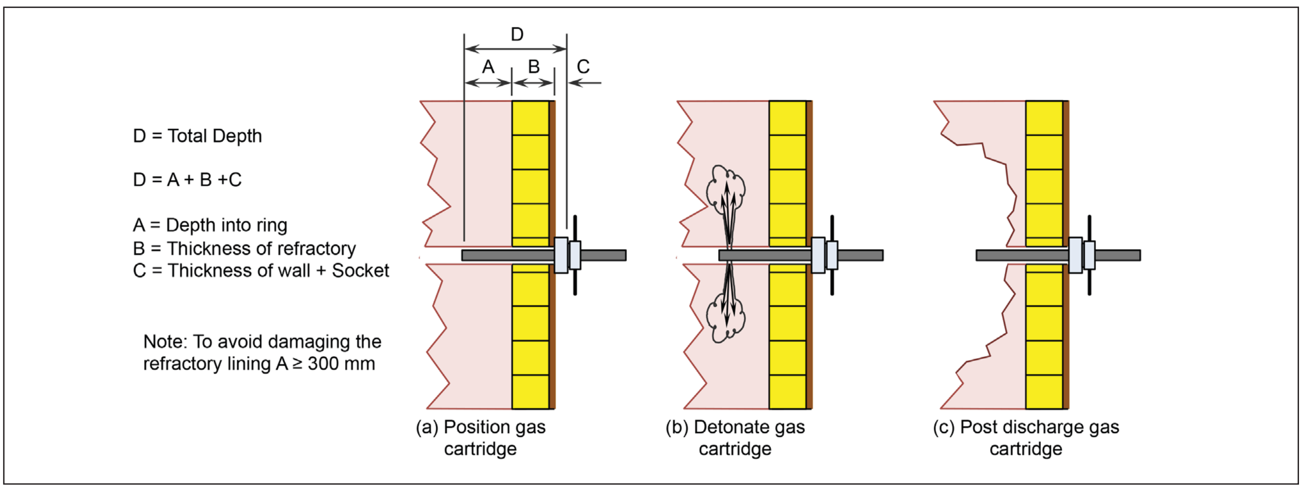
Thermally induced stress cycling (thermal shock) is another technique used to remove rings. In this case, the operators change the operating conditions to alter the temperature profiles along the kiln. Provided the operators detect the ring at an early stage and it has not hardened, the stresses generated by the differential expansion resulting from the changes in the temperature profiles along the kiln often exceed the strength of the ring, causing it to crack. Once this happens, it will fall out. Cycling the exit gas temperature and O_2 or shutting off the mud feed and the burner are two approaches commonly used to induce thermal shock. The use of thermal shock is more effective in removing dust and mud rings at the back of the kiln. This approach is less effective in removing mid-kiln and burning zone rings.

Once a ring grows to be 3–4 m (9.8–13.2 ft) in length with a thickness over 60 cm (23.6 in.), the use of shotguns or thermal cycling is not effective as a means to remove them. In these cases, non-explosive CO_2 ring removal systems (referred to as cardox systems) are used [8]. Initially developed for use in coal mining in the UK, this technology has proven to be a fast, safe, and cost effective way to remove rings. This technology utilizes a pressure wave generated by sudden expansion of CO_2 gas to dislodge the ring. The remainder of this paper will discuss this technology as a means to remove large rings.

CARBON DIOXIDE RING REMOVAL SYSTEMS

A schematic of the CO_2 gas cartridge used to remove rings in kilns is shown in **Fig. 7**. The cartridge is comprised of a high-strength steel tube filled with liquid CO_2, an electrode in the firing head, a chemical heater, and a rupture disc in the discharge head. The electrode is used to generate a small electric charge that activates the chemical heater that converts the liquid CO_2 into a gas. Once the cartridge is activated, within a few milliseconds, the volume of CO_2 builds up until the pressure inside the cartridge causes the rupture disc to burst, releasing the gas. The thickness of the rupture disc is varied to generate controlled discharge pressures up to 2760 bar (40000 psi). The forces generated in this approach are capable of dislodging most rings. In using this equipment, there is no risk of igniting any gas present in the kiln, as all combustion is carried out within the gas cartridge. Also, the pressure drop associated with the rapid expansion of the gas lowers its temperature, thereby preventing any gas/air mixture from igniting. The gas cartridge is not considered an explosive.

9. Photographs showing installation of socket on shell used for the CO_2 ring removal system: (a) magnetic drill press used to machine hole in the kiln shell, (b) 63.5 mm (2.5 in.) access hole used to insert the gas cartridge, (c) socket and safety cap used for gas cartridge, (d) welding socket to the kiln shell, and (d) final installed socket on shell for gas cartridge.

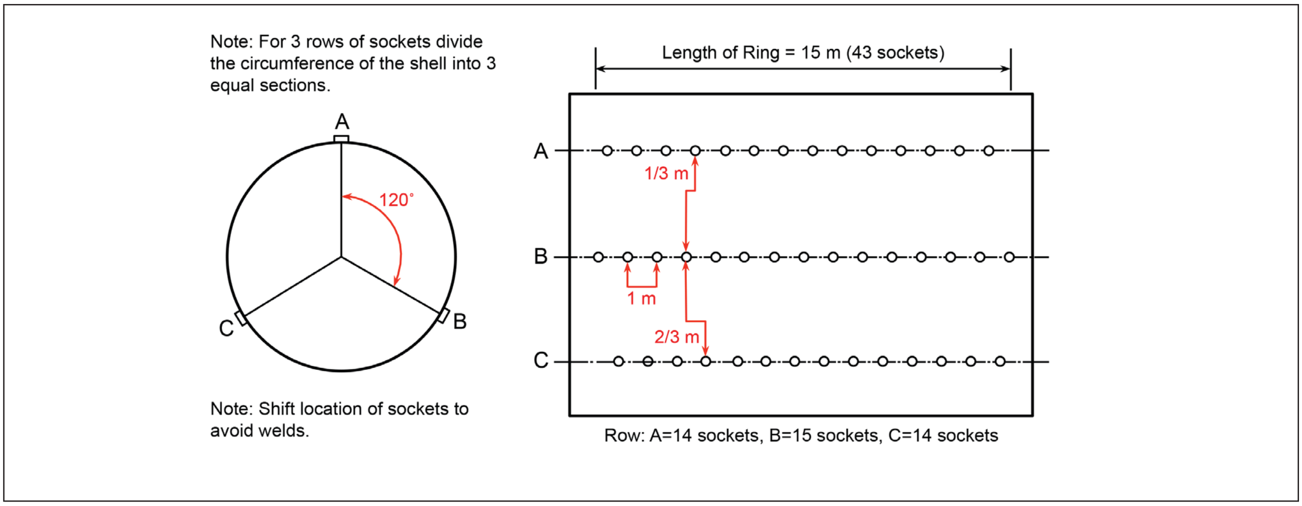


10. Schematic showing gas cartridge used to dislodge a ring: (a) the discharge head on the gas cartridge must be located inside the ring, (b) detonating the gas cartridge forces high pressure gas to expand into the pores of the ring, causing it to fracture, (c) remains of the ring following detonation of the gas cartridge. To avoid damaging the brick, the discharge head should be inserted at least 300 mm past the inner surface of the refractory lining.

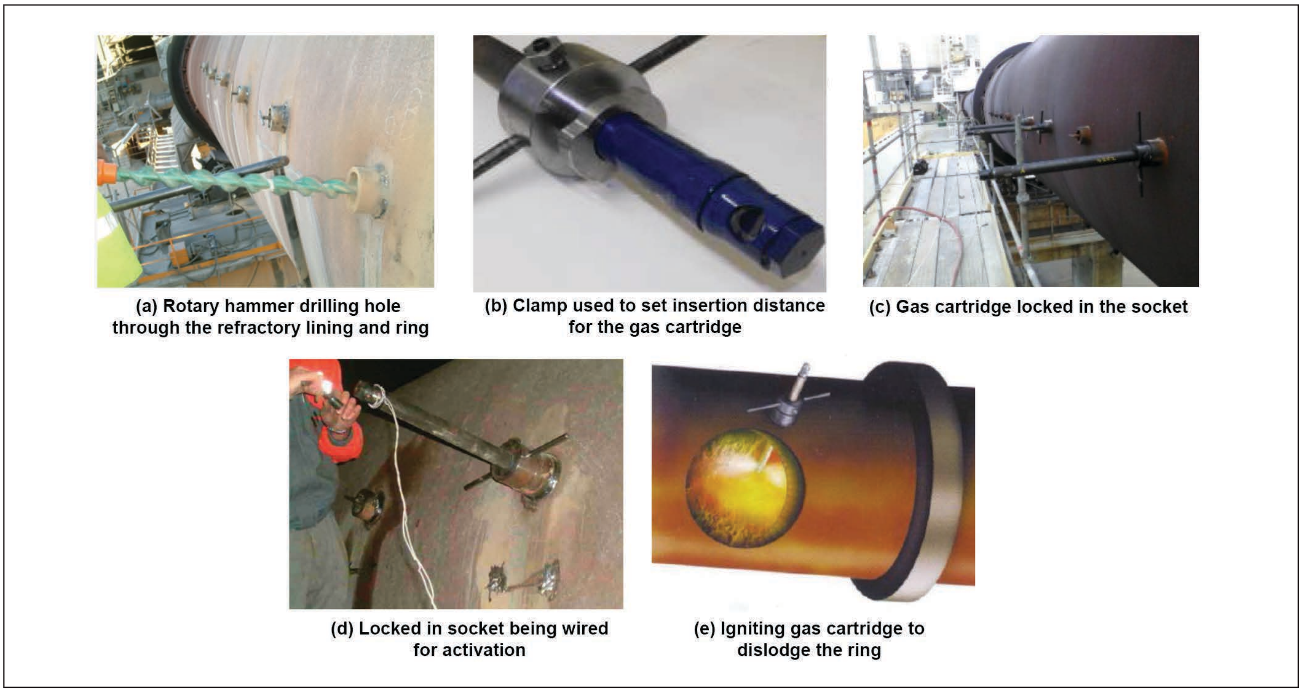
However the chemical heaters are recognized by Alcohol, Tobacco, and Firearms Regulations in the U.S. to be an explosive compound. This is not the case in all countries. The gas cartridges can be reused by replacing the chemical heater and rupture disc and refilling the tube with liquid CO_2. A photograph of a 50 mm (2 in.) outside diameter (O.D.) x 1.25 m (49 in.) long gas cartridge is shown in **Fig. 8**.

To remove a ring, the CO_2 gas cartridge must be inserted through the kiln shell into the ring. At each location of interest, an electromagnetic drill press is used to machine a 63.5 mm (2.5 in.) hole in the shell. A socket used to anchor the gas cartridge in place is then welded to the shell. Photographs showing the steps involved to install a socket are shown in **Fig. 9**.

The schematic in **Fig. 10a** shows the position of the gas cartridge relative to the ring when inserted into the kiln. To be effective, the discharge head of the gas cartridge must remain in the interior of the ring. As illustrated in Fig. 10b, this forces



11. Layout of sockets on kiln shell used to dislodge ring. Two to three rows of sockets are installed along the entire length of the ring. The centers of the sockets are located 1 m apart.



12. Photographs showing the steps to remove the ring: (a) rotary hammer drilling hole through the refractory lining and ring, (b) clamp used to set insertion distance for the gas cartridge, (c) gas cartridge locked in the socket, (d) locked in socket being wired for activation, and (d) energized gas cartridge to dislodge the ring (photographs and schematic courtesy Force Vector Inc.).

the high pressure CO_2 to expand through the pores in the ring, causing it to fracture. As Fig. 10c shows, keeping the discharge head at least 300 mm (11.8 in.) away from the bricks acts to protect the refractory lining.

The positions of rings are generally in well-defined sections of the kiln. The sockets used to remove rings must be installed in these sections. Standard procedure in most installations is to install 3 rows of sockets equally spaced around the circumference of the kiln with a center-to-center spacing of 1 m (3.3 ft). Adjustments in the placement of the sockets are made to avoid the circumferential and axial welds on the kiln shell. The sockets should be at least 150 mm (5.9 in.) from the nearest weld. The layout for a typical installation is shown **Fig. 11**. Installation is normally done during a major maintenance shutdown.

Rings should only be removed when they become large enough to interfere with kiln operations. To remove a ring, the kiln must be stopped, giving access to the socket in the location of interest. The safety cap is then removed. Next, a rotary hammer drill is used to drill a hole through the refractory lining and the ring. A bent piece of 6 mm (0.24 in.) rod is used to carefully measure the thicknesses of the ring and refractory lining. The clamping ring is then placed on the gas cartridge to set the position of the discharge head. Next, the gas cartridge is inserted into the kiln and secured in the socket. The electrical connections are then completed, with the exception of closing the circuit. Finally, the area is cleared of personnel and the cartridge is activated. Photographs showing the steps involved to remove a ring are shown in **Fig. 12**.

Following detonation, the gas cartridge is removed, the safety cap is put back in place, and the kiln is put back into service. The rings will normally fall out once the kiln has been restarted. Multiple detonations in both the axial and circumferential directions may be required to remove the entire ring.

STRATEGY AND PHILOSOPHY FOR DISLOGING RINGS

Upon making the determination that a kiln ring has started to interfere with operations, thought must be given on how to remove it. If the ring is over 5 m (16.4 ft) in length, it is not wise to remove the entire ring with one session. Depending upon the geometry of the kiln discharge, the material dislodged from the ring may plug the discharge hood, requiring the repositioning of the firing shield and/or burner to clear the debris. Removing 1–2 m (3.3–6.6 ft) of the ring one day and the remainder the next day may be more desirable.

Shell temperature measurements should be used to locate the ring. The socket on the downhill end of the ring should be the first one used to remove the ring. After the first shot, check the ring thickness using a bent metal rod. If the first shot cleared this section, move uphill to the next socket. After 3 shots, the kiln should be turned a few revolutions to clear the dislodged ring material from the ring location.

If the ring is more than 800 mm (31.4 in.) thick, it may be preferable to only remove 300–400 mm (11.8–15.7 in.) off the surface of the ring. This can be accomplished by setting the discharge head of the CO_2 cartridge to a distance above the refractory surface of 400 mm. This position should leave approximately half of the ring depth attached to the kiln refractory. In practice, this is unpredictable. The force of the released CO_2 may fracture more of the ring than anticipated and break the entire ring away from the refractory. If your desire is just to remove the downhill portion of the ring, fire two shots in one row and then reposition the kiln to the next row and fire two shots in that row.

After dislodging the ring, restart the burner and bring the kiln to operating temperature. As the ring pieces move to the discharge end, some of them will break up. If the discharge end is overburdened with the large pieces of the dislodged ring material, there must be a plan of action to address this issue.

It is always more desirable to correct or eliminate the root causes of ring formation, but where these efforts fail to fully address or mitigate rings, the option to have a ring removal system is attractive for a number of reasons. The most pronounced reason is that use of this technology completely eliminates the requirement for a lengthy shutdown to manually remove a ring. Avoiding the additional expenses of operating the plant with 100% purchased lime for several days is another issue that supports utilization of this technology. Also, not having to enter the kiln with personnel eliminates the potential for a safety incident.

REGULATORY ISSUES

There is some resistance to utilizing this equipment that is not related to technical issues with the application. These are the regulatory and permitting issues in the United States. The U.S. Department of Transportation and U.S. Bureau of Alcohol, Tobacco, Firearms, and Explosives regulate the transportation and storage of the chemical heaters from some suppliers. The chemical heater is the component that generates the high pressure responsible for the heaving force that dislodges the ring material from the kiln refractory. The regulations governing the use of the chemical heaters are dependent upon the country of manufacture and the country of use and storage of the chemical heaters. There are also some local jurisdictional requirements and permits for storage of the chemical heaters in the U.S. Suppliers of the chemical heaters are the best resource for determining with which regulations the users are required to comply.

CONCLUDING REMARKS

- Ring formation occurs in the rotary kilns used by the pulp and paper industry.
- The main types of rings include: burning zone rings, mid-kiln rings, dust rings, soda balls, and mud rings.
- The exact mechanisms for formation are not completely understood. Rings are typically found in areas where the gas, solids, or refractory lining are around 800°C. This is a key temperature in terms of forming the liquids needed for the formation of nodules and rings. Mud rings are the exception. These rings are caused by wet mud exiting the chain section.
- While it can be very small, all kilns have a mid-kiln ring. The formation of this ring is tied to nodule formation.
- Dust rings are the most problematic. These rings can very quickly assume massive proportions, restricting the flow of gas and solids in the kiln.
- Making progress on reducing ring formation requires a continuous effort to improve kiln operations over an extended period of time. The key factors in minimizing ring formation include reducing process upsets and lowering dust levels.
- In mills where ring formation is a recurring problem, the use of mechanical ring removal systems should be considered.
- Once a ring grows to be 3-4 m in length with a thickness over 60 cm, it can be very difficult to remove. In these cases, CO_2 ring removal systems can be used. This technology utilizes a pressure wave generated by

sudden expansion of CO_2 gas to dislodge the ring.

- While not focused on the root cause, CO_2 ring removal systems have proven to be a fast, safe, and cost effective way to dislodge rings. Using this approach will typically dislodge a ring in a few hours as opposed to shutting the kiln down for several days to remove the ring. **TJ**

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We have worked in the pulp and paper industry for 30 years. We chose to research this topic because lime rings in rotary kilns have plagued the industry since rotary kilns were placed in service. Previous research has focused on why and how rings form, but even knowing the chemical or mechanical reasons that rings form may not allow operators to avoid them.

The most difficult aspect of this research was obtaining representative process data. The mills record and have data for operational and accounting requirements, but to perform system analysis, more detail is required.

This paper focuses on the mechanics and use of CO_2 systems to remove lime rings. While such systems have been used by some in the pulp and paper industry for more than 30 years, they have not been widely adopted for a number of reasons.

In mills that experience severe kiln rings and have not determined the root cause, CO_2 systems should be considered. Our next step is to examine methods used by other industries to remove rings.

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