Lessons Learnt and Performance – Installing and Commissioning an Ausenco Carbon Reactivation Kiln in Africa

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ABSTRACT

A gold mine in north-eastern Africa has expanded throughput from 5 to 10 Mt/y in recent years. The original carbon regeneration kiln was incapable of achieving required throughput or meeting process conditions to reactivate the carbon due to heavy fouling by high molecular weight frothers and collectors. A new high temperature kiln was required.

The design criteria for the carbon reactivation kiln and associated equipment were revised, then implemented in close cooperation with a kiln vender who had previously supplied kilns operating successfully on highly fouled carbon. The result is a whole facility, holistically designed to achieve the technical criteria.

The new carbon reactivation facility has been operating since 1 July 2014. What have we learned? What has performed to expectations? What could be done better?

This paper presents lessons learnt regarding the design, implementation, operation and maintenance of the Ausenco Carbon Reactivation Kiln. 'Lessons' are associated with threats and opportunities (risks) that have that have been realised. The importance of identifying and managing risks for even small straightforward projects is made.

INTRODUCTION

"If the use of some new … type of equipment … is absolutely essential to the economic viability of the plant, go ahead" (Halbe, 2009). Innovation is not optional, but essential in creating value from increasingly low grade ore deposits (Marsden, 2009). Marsden has also suggested that the only way to avoid prior mistakes is to incorporate and embrace innovation in the design process, and provided a process to evaluate innovation in terms of risk and reward. An innovation with high risk / low reward is a 'No-Go'. Innovations with high risk / high reward or a low risk / low reward need careful evaluation. A low risk / high reward innovation is considered a 'no brainer – Yes' decision. For a brown-field operation, new equipment affords the highest opportunity for innovation and value creation, but can also be associated with high risk (Marsden, 2009).

The replacement of a low temperature carbon regeneration kiln with a high temperature reactivation kiln to cope with a major mill upgrade and carbon from both flotation tails and flotation concentrate leach circuits was deemed a 'no brainer'.

In 1985 the principle author began using the values in Table 1 to guide projects and ensure elements of a project were not overlooked. The priority of the middle and bottom values shift somewhat, but generally the priorities are as presented in the table. Seven of these values are identified by Marsden as 'drivers for innovation' (Marsden, 2009). Innovation introduces risk and the economic benefit to the client must warrant taking that risk.

Table 1: Generic Client Project Values

Priority	Value	Clarification
1	Health & Safety	The health and safety of people is not to be compromised. Safety risks to assets are to be identified and an informed decision made.
2	Legal & Regulatory	Identify and comply with all laws and regulations.
3	Corporate Initiatives	The directors are empowered to apply assets and usually have good reasons - support their initiatives.
4	Product Quality	If intermediate or end products are not too specification, then equipment is not fit for purpose (no matter how cheap it was to buy!)
5	Capital Expenditure	Plant must be fit for purpose for minimum capital cost
6	Throughput	Increases saleable product and reduces unit cost
7	Yield	Increases saleable product and reduces unit cost
8	Operating Cost	Important as head grades drop and processing becomes more complex – costs add up.
9	Operability	Improves almost all of the above – do not ignore!
10	Maintainability	Improves almost all of the above – do not ignore!
11	Constructability	Design and engineer keeping delivery and commissioning in mind in addition to other drivers

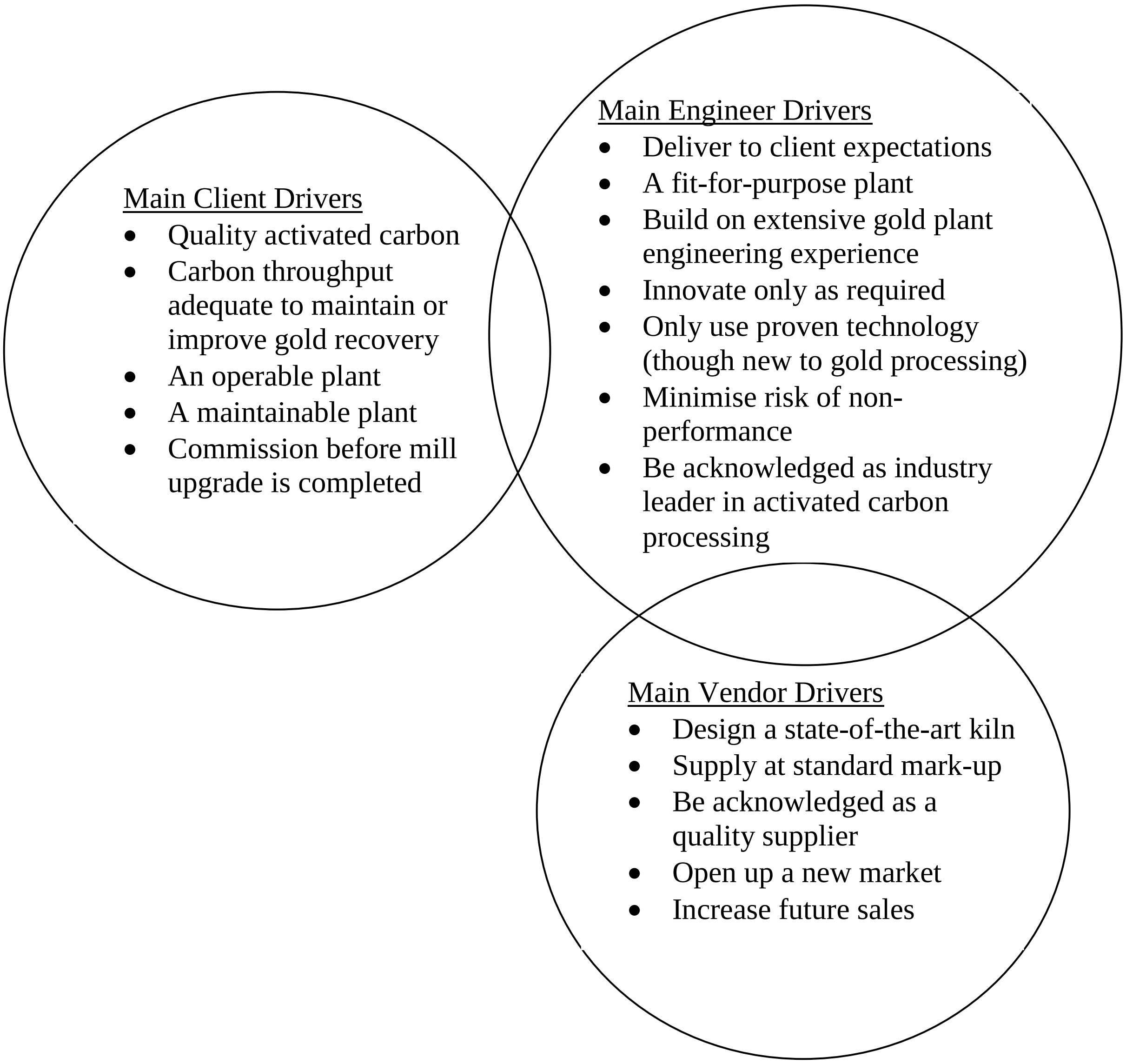
When the client values/drivers are qualitatively applied to the project in question the following drops out:

1. Health and safety issues included process off-gases, materials of construction, equipment high temperature protection, access for maintenance and the need for a special purpose safety induction.
2. Compliance with environmental licence conditions was the only other legal issue considered relevant to the kiln upgrade.
3. No specific corporate initiatives were identified.
4. Quality activated carbon to improve yield was a high priority.
5. Capital expenditure was not, initially, a major driver.
6. An increase in mill throughput was the major driver as the original kiln would be overwhelmed
7. As plant throughput overwhelmed the original kiln, gold recovery would reduce due insufficient gold loading capacity of the carbon
8. Operating expenditure of the new kiln would be high if heat losses were not minimised and no recovery performed, but increased operating cost was deemed to be less than the cost of replacement carbon as required if the old kiln remained in service.
9. Operability issues focused primarily on the ability to achieve the required process conditions

10. Maintainability was considered relative to the original kiln and not a focus
11. Constructability focused on the need to ‘shoe-horn’ the new facility into the very small land area available within the existing processing plant.

Independently, the engineer identified that cooperation between the client, the engineer and the kiln supplier was a key risk because of their inherent conflict of interests (refer to Figure 1). Significant energy was invested into the client-engineer and engineer-kiln supplier relationships.

The ‘lessons learned’ presented in this paper are threats or opportunities (risks) that were realised. Design reviews, HAZID and HAZOP studies were performed, but note that no overarching project risk review was carried out. The threats that were realised were largely risks not identified and therefore not mitigated.



Main Client Drivers

- Quality activated carbon
- Carbon throughput adequate to maintain or improve gold recovery
- An operable plant
- A maintainable plant
- Commission before mill upgrade is completed

Main Engineer Drivers

- Deliver to client expectations
- A fit-for-purpose plant
- Build on extensive gold plant engineering experience
- Innovate only as required
- Only use proven technology (though new to gold processing)
- Minimise risk of non-performance
- Be acknowledged as industry leader in activated carbon processing

Main Vendor Drivers

- Design a state-of-the-art kiln
- Supply at standard mark-up
- Be acknowledged as a quality supplier
- Open up a new market
- Increase future sales

Figure 1 Stakeholder Drivers

BACKGROUND

As a gold mine moves from processing oxide ore to sulphide ore, flotation is often used to concentrate the gold containing sulphide material before leaching. Some of the reagents used are adsorbed onto the activated carbon in the adsorption circuit, reducing the carbon activity and taking up adsorption sites. More activated carbon is added to the circuit to offset the reduced carbon activity and provide more sites for the gold to adsorb onto. If the reagents are not removed, then the carbon activity continues to degrade. Ultimately, fouled carbon is removed from circuit and fresh virgin activated carbon is added to maintain overall recovery.

The engineer was approached by a mine processing low grade primary sulphide ore through flotation and CIP as they were planning an expansion to increase nominal throughput from 5 Mt/y to 10 Mt/y. The original kiln was only suitable for treating lightly fouled carbon, such as from oxide ore processing. The kiln operating conditions were taken to their design limit, but the kiln could not provide the residence time at the extreme operating conditions required for heavily fouled carbon. Loaded carbon activities dropped to around 10% of virgin carbon, improving to around 40% after regeneration (Claflin, La Brooy and Preedy, 2013). The kiln could not sustain operation at these extreme conditions and required a near complete rebuild. To compensate for the inadequate kiln performance many hundreds of tonnes of fouled carbon was removed from the circuit and accumulated on site.

The plant in question has both flotation concentrate and flotation tails leach circuits. Carbon that spends a long time in the circuit, such as in a floatation tails leach, has the opportunity to load flotation reagents that will not be displaced by gold. Hence the gold loading of a flotation tails leach will be more severely affected than in a flotation concentrate leach circuit, where the carbon would be exposed to the same reagents for a much shorter time (La Brooy and Bax, 1985, Mahapatra, 2009).

Potassium Amyl Xanthate (PAX) is used at this mine site as a collector. Figure 1 (after La Brooy et al., 1986) shows the residual carbon activity after 24 h exposure to 20 mg/L of different collectors Increasing the collector concentration further reduces the carbon activity. Frothers, can have an even more severe effect on carbon activity, with 24 h exposure to 20 mg/L frother reducing carbon activity to 10% of fresh carbon (La Brooy et al., 1986). Mahapatra (2009) observed frother induced reductions in carbon kinetic activity to around 4% of the control (Mahapatra, 2009)!

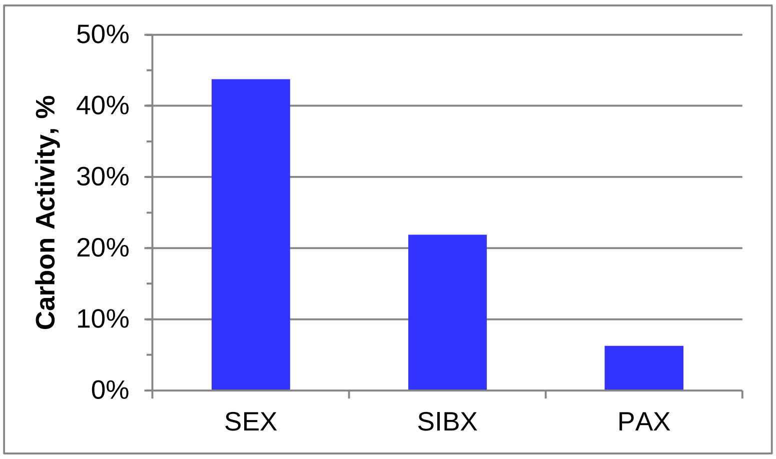


Fig. 1 - Relative carbon activity after 24 h in 20 mg/L of different xanthate solutions

Avraamides and La Brooy (1987) have summarised the required kiln temperature and atmosphere requirements for effective thermal reactivation. Figure 2 (after Avraamides and La Brooy, 1987) illustrates the effect of temperature and time. It can be said that for carbon temperatures up to 700°C regeneration (stripping) occurs, while above that temperature carbon reactivation occurs (La Brooy and Claflin, 2013).

The reagents used by the client do not volatilise from the carbon, but rather decompose by pyrolysis at kiln temperatures used for oxide ore carbon regeneration, resulting in a carbonaceous residue on the activated carbon surface (La Brooy and Claflin, 2013). The carbon particles must be held for at least 10 min at over 750°C in a water vapour atmosphere for selective oxidation of the pyrolysed residue and therefore higher reactivation to occur (Avraamides and La Brooy, 1987).

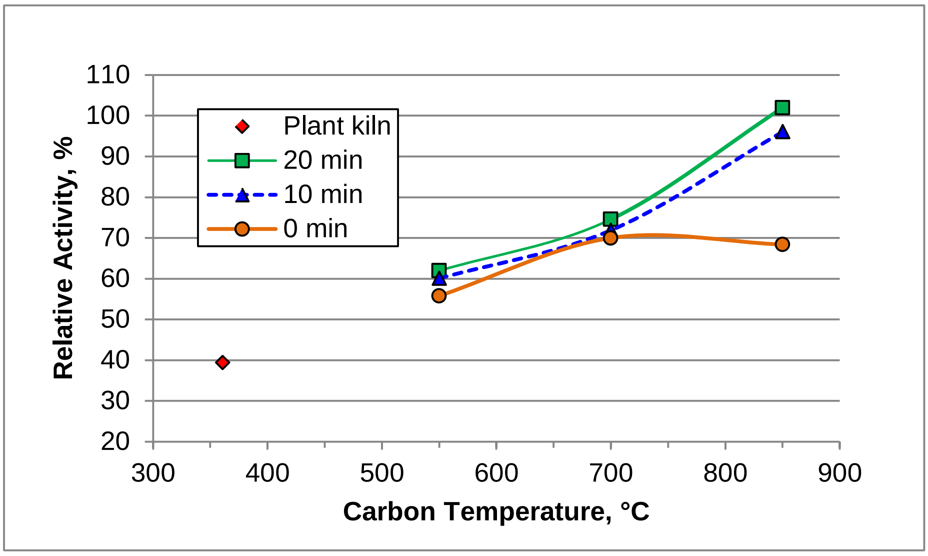


Fig 2 - Effect of time at temperature in thermal reactivation in steam atmosphere

The plant in question uses seawater for plant raw water. Carbon samples from a plant operating with saline water will show a higher relative activity in saline water than if tested in pure water (La Brooy and Muir, 1994). Furthermore the site uses an in-house carbon activity test. In-house laboratory results will therefore not be comparable with external laboratory results, but may be comparable to other in-house laboratory results (within the limitations of the procedure).

In-house carbon activity results for 2011 are presented in Figure 3 prior to a major mill upgrade. Towards the end of that period, the mill throughput increased from 3 to 5 Mt/y. The relative carbon activity dropped from 80 to 90% to become variable between 50 and 70%. It is worth noting that in June of 2011 carbon samples were sent for external analysis. External testing reported the regenerated carbon activity to be 34 to 43% (Wardell-Johnson and Barbetti, 2011a & 2011b) at a time when in-house testing suggested activities of the order of 80%.

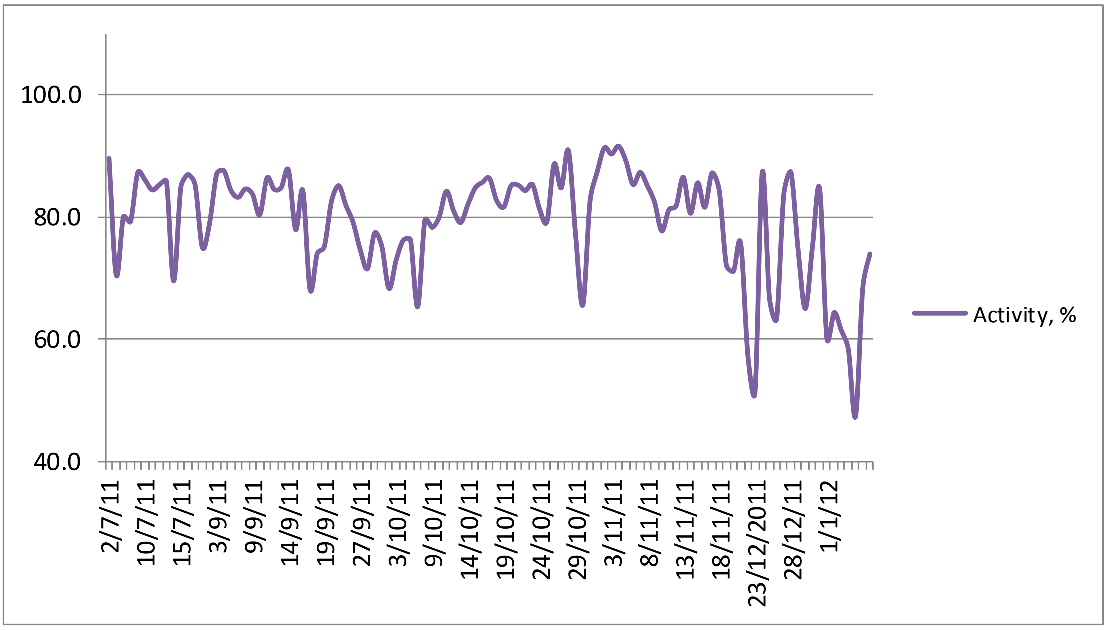


Figure 3 - Carbon Activity Pre Major Mill Upgrade (in-house test procedure)

PROJECT RISK LESSONS LEARNT

Project Risk Assessment

The project was small and expected to be of a short duration, hence a broad project risk assessment did not take place. This was an oversight.

A project risk assessment should not be optional. It should be initiated early in the project lifecycle and updated as the project progresses. Its purpose is to raise awareness of potential threats and opportunities so that value can be maximized by implementing opportunities and avoiding or mitigating threats. The depth and breadth of each assessment is commensurate with the number and severity of consequences remaining in the project.

The kiln upgrade project consisted of an investigative study, a scoping study, and detailed engineering followed by ongoing support of the client during procurement, construction and commissioning phases. The initial project risk review could have been performed as part of the scoping study and reported in a single day.

A project risk assessment would generally cover the following issues:

Location: Country, Weather, Communications, Logistics
Sociopolitical: Stability, Rule of Law, Changeability, Education, Culture, Religion
Environmental: Regulations, Pressure Groups, Enforcement
Client: Ownership, Management, Experience, Involvement, Culture
Commercial: Funding, Conditions, Liabilities
Contractual: Strategy, Scope, Major Contractors, Liabilities, Responsibilities
Project Program: Planning, Project Management, Integration, Performance
Resources: Management, Continuity, Industrial Relations, Materials, Capability
Definition Phases: Suitability, Novelty, Design
Delivery: Procurement, Construction, Schedule, Budget, Commissioning
Operation: Operability, Maintainability, Operational Readiness, Security

Certainly the technical novelty was a known and managed risk, however, many other project risks were either not identified or not adequately mitigated.

Of significant impact was a change in the political situation and associated change in law, which impacted both fiscal and logistic aspects of the project and contributed to a number of project delays. Whilst this change in the political situation of the country could not be known in advance, the possible delay to the project as a consequence of civil unrest could have been surmised. A suspected delay in the project would have raised the possibility of losing key personnel and the importance of having strong corporate and site management support for the project through implementation. In fact, for the project in question, the project champion left the site for personal reasons before the kiln was constructed.

Workforce technical capabilities, or lack thereof, were not sufficiently identified for the engineering principals of the project. Assembly of the kiln was performed in-house but was not performed well, with a majority of the unit operations requiring some kind of modification or repair during the commissioning process.

The automation system, typically the most complex aspect of any project, experienced a significant amount of issues. Re-wiring of drives, repairs to cabling and repairs to the Profibus communication system all occurred after commissioning commenced. The automation program was Factory Acceptance Tested based on a centralized system, but it was decided immediately prior to commissioning to control the facility from a local PLC, the software for which had not been written or tested. Operations had a predilection for manual control and would use only the most basic of automatic control in any case. Manual control works, but is much more difficult and is not efficient or as effective.

Had even a high-level risk assessment taken place, the design would have been significantly different. Project complexity and automation would have been minimized to be in line with the sophistication of the workforce and site management practices.

TECHNICAL LESSONS LEARNT

Sand trap

An extraordinary amount of sand and grit exists in the carbon circuit, nominally 20 to 30% by volume or 50% by mass (dry basis). The inorganic material displaces carbon in the acid washing and elution columns, thereby requiring more batches to be processed in order to provide sufficient carbon for adsorption. Consequently the kiln must treat much higher mass throughput rates to produce the amount of carbon needed for processing.

A simple gravity separator was designed. The criterion was to remove as much sand as possible and lose essentially no carbon. Larger grit settled in a 10 m tall teeter column where a rising water flow elutriated carbon upwards. Carbon and smaller grit particles reported to the overflow and passed to the dewatering screen. Sand and grit was discharged via a double dump valve immediately under the elutriation leg.

The flow rate to the sand trap was greater than design in an attempt to prevent sanding in the supply piping. An additional 100 mm of freeboard was required on the sand trap to prevent overflowing.

During commissioning the sand trap did separate grit from the carbon very successfully, but not for very long. The excessive sand content required the double dump valves to work continuously on a very short cycle in order to discharge sand. When the valves closed, they closed on a packed column of grit and ceramic mill media. The ceramic media eventually got caught in the seat of the valve (between the ball and the valve housing) and jammed the valves open, dumping sand and carbon into the bund. Pinch valves were tried without success.

The sand trap was bypassed during commissioning and operations have not yet returned to it. An air lift on the discharge may avoid the problems and be capable of operating continuously with the consumption of just 5 m^3/h of additional water.

The downstream equipment was designed to have significant sand associated with the carbon, but not to the degree experienced. Acquiring representative samples of the feed and characterising them in terms of composition, solids handling and pumping is a lesson learned.

Carbon dewatering screen

The overflow from the sand trap to the dewatering screen did not have sufficient fall and sanded up. Construction verification should be performed by commissioning to ensure that what is constructed is as per design and fit for purpose.

Aside from construction issues, the dewatering screen received, washed and discharged carbon (with sand) satisfactorily. The instantaneous rate was 65 m^3/h and contained 35 t/h/ of carbon and sand. Screen apertures were 0.63 x 18.5 mm. The screen width was 1.2 m and the length 1.8 m. Had only carbon been in the feed, the instantaneous specific feed rate would be 10 t/h (dry, 20 t/h wet). The carbon was not fully dewatered as additional dewatering was allowed for from the hoppers.

Kiln feed hoppers

The design incorporated two kiln feed hoppers. A slide gate at the bottom of the hoppers was removed as it is unnecessary. Solids simply build up on the small screens under the hoppers and drain. After the charge has completed draining, the screen is turned on/off to discharge solids to maintain level in the feeder hopper below.

Ideally the feeder screens should have their vibrating weights adjusted or VSD tuned so that solids discharge almost continuously to permit downstream equipment to have a chance at functioning.

Pre-Dryer

If the feed is steady, then a small flash dryer will receive, dry and discharge the feed to the feeder hopper. Tuning of the feed system was not completed during commissioning and operations have not returned to commission this feature and are instead considering a completely separate pre-dryer.

Kiln feed system

The feeder hopper maintains a level above the vibrating tube feeder. The level is important to prevent off-gases back flowing into the feeder hopper. The tube feeder should be inclined slightly upwards to also prevent gas flowing back into the feeder hopper and overheating (melting) the vibrating gas seals.

Because the pre-dryer was not commissioned, the bypass was always used. The height the bypass enters the feeder hopper is low and the level sensors were not suitably placed to measure the feeder hopper level when being supplied by the bypass. Furthermore, the bottom most level sensor was on the cone and entered the feeder hopper at an upwards incline. Salt water and carbon accumulated in the socket, which on heating, corroded the instrument. The socket was made horizontal and self-draining to avoid the problem.

If a significant amount of sand is present, then the sand builds up in the tube feeder and the weight dampens the vibration, which reduces the flow rate and exacerbates sand build-up. Furthermore, off-gases flow outside the tube feeder inside the kiln. The off-gas temperature is very high and the tube feeder heats up resulting in evaporation inside the tube feeder. If sand is present, then salt crystals develop which cements the sand and leads to a blockage.

Tube feeders are used successfully to feed reactivation kilns elsewhere, but given the quantity of sand present and the preference for manual operation, a screw feeder should have been used despite the damage to the carbon.

Reactivation kiln

The reactivation kiln itself has performed well above design despite inadequate operation of equipment all around it. The kiln was designed to reactivate 1.5 m^3/h (750 kg/h) of carbon. To keep the feeder from blocking, the feed was maintained at 2 m^3/h. The equivalent dry mass rate is 1500 kg/h (50% grit and 50% carbon). Despite doubling the mass rate, the reactivation temperature is still being achieved. The key is that conventional lifters were not used, rather numerous heat transfer fins were installed and the fill ratio increased to 40%. This permits the heat from the 950 to 1050°C combustion chamber to transfer by conduction into the carbon bed at an optimal rate.

Due to damage caused when unpacking the kiln, re-alignment was required. No procedure was supplied and on inspection it was found that the kiln seals could not be re-aligned as supplied. Modifications were required.

The fuel supply train was supplied using poor quality components, e.g. the main fuel filter was supplied with a gasket that disintegrated in diesel and blocked all five downstream burners. All burners were identical even though they all operate at different duties – this is a good lesson as spares and method of operation are shared even if they are set up slightly differently.

The fluid bed cooler hangs off the kiln discharge hood to allow for kiln expansion while maintaining the hot end gas seal. Two springs were used to pull the hood and cooler up to the drum and they were insufficient for the task. Even so, each spring was very dangerous to install – a pneumatic ram with pressure relief to allow for drum expansion would have been a better option. Having the cooler suspended with, and travelling with, the discharge hood as the kiln expands is a good lesson, if the drum seal can be kept pulled up. If not, the seal falls out and delays are incurred until the kiln is cool enough to re-install the seal rope. If a floating seal is used, then in order to keep oxygen out, the kiln should be under slightly positive pressure, which introduces health risks.

The discharge hood design in this project permitted easy access to the hot end of the kiln. The discharge hood was on a trolley that was pulled by springs to effect a gas seal with the rotating drum. If the springs were relaxed, the hood could be rolled 500 mm away from the drum. Access was lost when a vapour duct was located in the path of the trolley during design, restricting the trolley movement. In a similar example of poor design, viewing windows were supplied but made unusable by the discharge hood's sub-frame (which was added to the design because of the need to support the mass of fluid bed cooler). There must be access for operations and maintenance.

Temperature of the carbon in the middle of the reactivation zone and at the discharge of the kiln was measured, but this did not provide good information on the temperature profile. Installing a longitudinal pipe to permit temperature measurement along the whole length of the kiln would permit more efficient and effective operation.

Steam from an independent boiler was used to cool the carbon in the fluid bed cooler. Steam flow was excellent, but during manual operation, too much steam could be added, which could cool the kiln and interfere with reactivation. To aid operation, much of the steam from the cooler was permitted to bypass the kiln directly to the stack.

Fluid bed cooler

The fluid bed cooler is a vertical chamber where steam is introduced from the periphery. Cooling steam feed rate is a function of the solids temperature. If operating manually and the conditions are changing, this is very hard to set and stabilise.

The cooler was also difficult to operate during commissioning due to incorrect construction with level and temperature instruments being supplied and located incorrectly. Rotating paddle type level switches suitable for 600°C were specified, but paddle switches suitable for 350°C were supplied installed by the vendor. One paddle switch was supplied so that it interfered with the internal wall. It could not be accessed for inspection or repair and always showed a level. A temperature probe intended for measuring steam temperature leaving the cooler was instead located in the falling solids stream from the kiln. Another temperature probe, intended to measure the solids temperature being discharged to protect downstream equipment, was far too short and permitted overly hot material to cause downstream damage.

If the fluid bed cooler stopped discharging, then carbon would overflow directly to the quench tank. This design worked quite well and indeed, could be modified to provide gentle cooling without a separate boiler (see Recommendations section)

Fines screen

The fine carbon screen is to capture fine carbon before it reports to the last tank, adsorbs gold and escapes to tails. Despite being intended to operate at 350°C, the vendor supplied plastic and cloth screen skirts and gas seals, which did not last long and allowed a localised fire when overly hot material was discharge from the cooler (because the wrongly sized temperature probe did not sense the temperature).

The fines screen was a 1 mm aperture wedge wire screen, 600 mm wide by 900 mm long. The screen was designed to have a bed depth of 7 mm. The actual depth experienced was closer to 40 mm as a result of the height of the fluid bed downcomer above the screen deck. More attention should be paid to the height of the feed above the screen. The screen was not appropriate for sand. The sand caused severe pegging. The screen should have been 50%

wider and 100 % longer to permit the bed to thin out, fine material to pass through and to allow for pegging. The screen should be designed to a specific area for 400 kg/h/m^2.

The fines screen oversize discharge reports to a static accretion screen located in the quench tank. When modified with the correct screen aperture and area, the accretion screen worked quite well. The undersize screen was bolted to the structure, which dampened vibration and affected control. The underflow was modified to reflect the original design.

The carbon return pump drew carbon and water from the quench tank. Because of the sand content, the recessed vane impellor pump had to operate at extreme speeds to produce the required discharge head and this resulted in severe pump erosion and carbon breakdown. The recessed vane pump was replaced with a larger, slower speed slurry pump which overcame the sand problem, but drew slightly more water than design from the quench tank.

Off-gas scrubber

In order to achieve stable operation, the kiln temperature was raised over the initial design temperature, which increases the water gas reaction rate. The amount of off-gas produced went up considerably and consisted of carbon monoxide and hydrogen. The off-gases report to a venturi scrubber and are drawn by a fan and discharged directly into the same stack as the products of combustion. At higher operating temperatures, a flashback occurred, which caused minor equipment damage and caused a plastic gas seal to catch fire. Though an incinerator was included in the stack design as a future option to deal with excessive non-condensable gases, the flashback was not picked up as a concern during the HAZOP.

The long-term correct solution is to modify the ducting and install the incinerator. However the expeditious solution was to install a separate exhaust stack and expel the off-gases to atmosphere. Incineration of the gases reporting to the separate exhaust stack will still be required to prevent any potential health hazards associated with off-gases. Needless to say, inadequate design of the exhaust system is a serious lesson to learn.

Carbon Activity

Figure 4 presents relative carbon activities of the regenerated carbon, measured using the in-house procedure immediately following kiln commissioning while the 10 Mt/y upgrade was ramping up. Importantly the site increased the kiln throughput to 1 500 kg/h of carbon plus sand (design is 750 kg/h of carbon) in October, hence the drop in activity from 100% to 90%. Increasing throughput stabilised facility operation and provided more capacity for gold loading in the leach circuit.

The data is not of high quality and, at best we can only conclude that carbon activity appears to be similar to virgin carbon and this is despite very high throughputs. The measured activity is not comparable to activities measured by other methods or from other laboratories, as there are no particle size or moisture corrections.

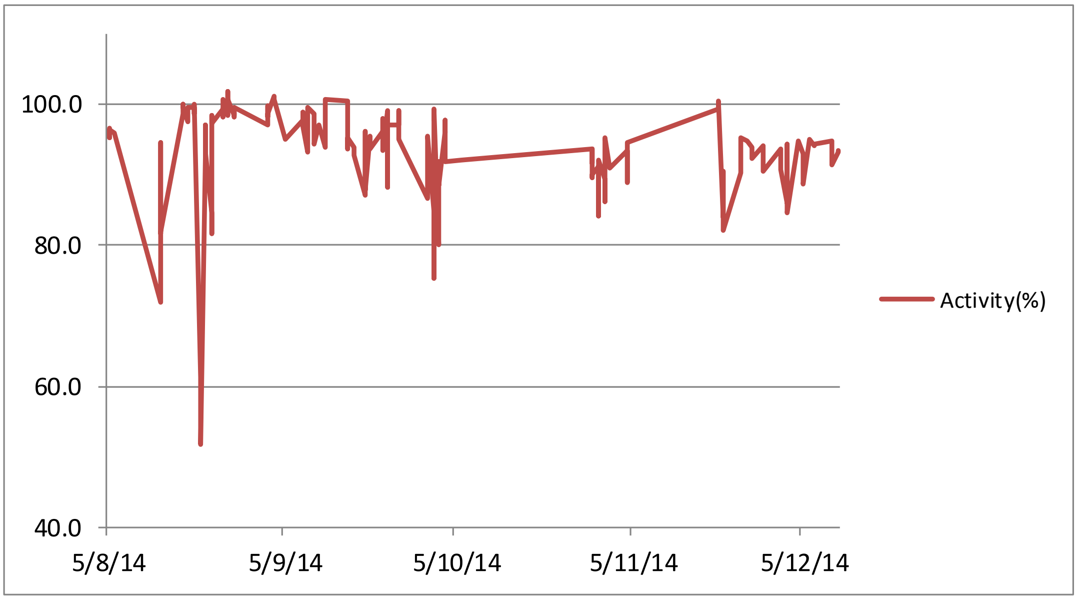


Figure 4: Carbon Activity post Commissioning (in-house test procedure)

CONCLUSIONS

The Ausenco Carbon Reactivation Kiln is reactivating above expectation, however:

1. For this site, the high temperature rotary carbon reactivation kiln facility, as a whole, was too complex
2. For this site, the level of automation was inappropriate
3. A project risk assessment should always be performed and acted upon
4. Project champion (project sponsor) and client management support is critical
5. Construction verification should be performed by an independent commissioning team to ensure construction is to design and design is fit-for-purpose
6. Characterise the feed, which in this case was as much sand and mill media as carbon.
7. Elevated temperatures greatly increase hydrogen and carbon monoxide off-gases, which need engineering solutions to avoid becoming health and safety incidents.

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