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OPERATIONAL AND ENVIRONMENTAL BENEFITS OF THE NEW BAKING FURNACE AT BOYNE SMELTERS BY USE OF AN ADVANCED FIRING TECHNOLOGY

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Abstract

In February 2012, a new baking furnace was commissioned at Boyne Smelters Limited (BSL) on Boyne Island, Australia. This new furnace replaced the production of two existing closed type furnaces and set new benchmarks in production performance.

The advanced firing technology is based on latest safety requirements of the Australian Gas Authority (AGA) gas standards. In parallel, new self-recovery network structures behind the wireless network have been developed to maximize the redundancy and availability of the system. Finally, intelligent control modules have been implemented for on-line optimization of the baking process.

This paper will outline the special technologies used and demonstrate the results that can be achieved to allow for smarter and cleaner baking cycles in combination with relevant safety standards and system availability.

Introduction

Now part of the Pacific Aluminium, Boyne Smelters Ltd. (BSL) is a primary smelter put into operation in 1982 by Comalco Aluminium and its joint venture partners. BSL over time has undergone extensive expansion. The smelter underwent a A$1 billion expansion in 1997 introducing a third reduction line which increased aluminium production from 260,000 to more than 550,000 tons per annum. The company has once again undergone a significant modernization with the re-building of Carbon Baking Furnace 3 (CBF3) and the construction of a new Carbon Baking Furnace 4 (CBF4) to upgrade the baking technology. The new baking furnace replaced the two existing closed type furnaces that were obsolete and fully outdated in terms of energy efficiency, emissions of greenhouse gases and high refractory maintenance and operational cost. An aerial view of the smelter is provided in Figure 1.

Figure 1:BSL on Boyne Island

Details of the Carbon Bake Furnace 4

The new baking furnace is an open-type Rio Tinto Alcan AP design. It consists of 66 sections, each with 9 flues and 8 pits. BSL operates 4 fire groups on this furnace. The configuration includes 3 sections in the preheat area, 3 sections in the firing area and 6 sections in the cooling area. Figure 2 shows the actual fire configuration.

Figure 2: New Firing System for CBF4 at BSL

The fire cycle time can vary between 24 and 32 hours, depending on the production requirements.

Advanced Firing Technology

The Advanced Firing Technology is a tailored system to suit the requirements of BSL. The control philosophy is based on the implementation of intelligent optimization modules on top of the basic automation for an optimum system using today's state of the art and future oriented technology.

The firing system provides the following features:

- Fully automatic system operation
- Preheat Control with complete internal pitch burn
- Automatic Cross Over strategy
- Safety interlocks according to Australian Gas Association (AGA) standards
- High pressure pulse burner technology
- Preparation of the equipment for fire direction reversal
- Simple and easy operation
- Advanced Control Modules for Firing Optimization.

In addition to the firing control system the following Auxiliary systems were implemented:

- Main Gas Supply Skid for furnace gas supply, including emergency stop (E-stop) circuit
- Fume treatment centre (FTC) data interface including main draught interlock
- OPC(standard data communication protocol) interface to plant wide Manufacturing Execution System (MES)
- Ring main duct explosion vent monitoring
- Start-up Burners for firing control below 750 °C

An overview of the operator control screen is shown in Figure 3.

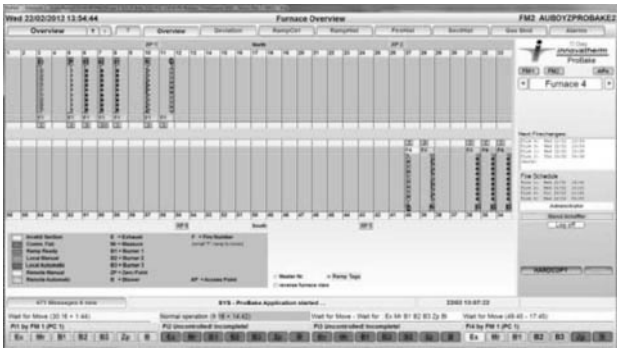

Figure 3: Fire configuration for CBF4

Safety Requirements for AGA

The firing and control system for the Boyne Smelter upgrade project requires extensive safety interlocks as per AGA and Queensland Government requirements.

Each of the local programmable logic controllers (PLC) executes process control functions. All (classified) safety interlocks are handled independently from the process PLCs and are realized by separate safety integrity level (SIL) 2 safety hardware. Safety signals are forwarded independently from the network infrastructure via a hardwired daisy chain to the respective system unit, as a result of a risk assessment and the HAZOP study with the AGA Queensland inspector.

The significant safety interlocks required to comply with AGA standards are:

- Hard-wired flue draught release for the burner ramps of the same fire
- High and Low Temperature interlocks at each burner ramp
- E-Stops for the Main Gas Supply Skid along the furnace bay
- Main draught release (from FTC) for Main Gas Supply Skid.

Beside these primary interlocks listed above, the following safety functionalities have been implemented for maximum operational safety:

- Tightness test of primary safety shut-off valves at the Burner Ramp before fire start and after each fire move
- Pipe tightness test at Burner Ramp before fire start and after each fire move
- Low Gas pressure supervision and cut-off at the Burner Ramp
- Emergency –Stop at each Burner Ramp
- PLC watch dog on each Ramp
- Automatic calibration of all draught / pressure sensors every hour
- Life Zero check for the draught / pressure sensors every hour

The combination of these additional safety features and interlocks leads to a significant increase of operational safety and a more reliable and sustainable production of anodes with respect to the baking furnace environment.

Self-recovery Control Architecture on Wi-Fi Bases

Due to the nature of the anode baking process the firing system consists of movable ramps performing the required firing discipline while the product remains at a constant position during the baking process.

Each ramp operating on the furnace is controlled by a local industrial PLC located inside the control cabinet of this particular ramp. All sensors and actuators are connected to this PLC. For local visualisation and backup operation an Operator Panel (HMI) is installed which interacts with the PLC and the connected instrumentation executing the required control functions for that particular ramp. With the help of the local HMI the operator is able to interact with the ramp locally in different operation modes on the furnace floor and monitor process and equipment status information (Level 1 control).

The automated control of the anode baking process requires data communication between each of the ramps forming a fire group as well as to the Level 2 Advanced firing control system and the MES located in the central control facilities. The communication system becomes an important key component of the firing control system.

Wireless communication became the logical state-of-the-art concept as the equipment in the field needs to be moved every day and a wired communication concept immediately creates reliability, operability and maintenance issues. However, the demand of a control system for anode baking furnaces results in very specific design criteria for the wireless communication system and equipment. The design as developed for CBF4 ensures a maximum availability of the system by implementing redundancy in combination with industrial Ethernet and wireless equipment.

The wireless network in the field is executed by four (4) stand alone industrial access points (AP) which work independently to each other to provide maximum redundancy. In the worst case, one AP is sufficient to provide the necessary communication between the ramps. Additionally the AP's are connected to each other via self-recovering fibre optic ring architecture through industrial Ethernet switches. The control architecture is illustrated in Figure 4.

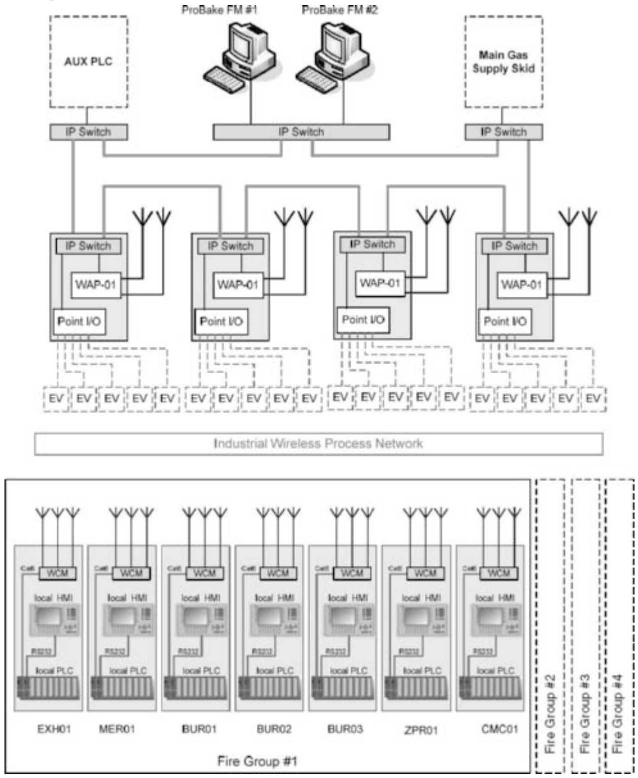

Figure 4: Self recovery network structures

Compared to public WiFi zones where the wireless infrastructure mainly provides access to the internet via a common gateway, in an industrial network mainly control components (PLCs and PC's) need to communicate to each other to exchange process and safety data within an industrial environment.

Since control components such as PLC's usually do not have a built-in wireless interface, special wireless client modules (WCM) are required to provide wireless connectivity of the firing ramps. Such WCM clients have been developed for the particular demands of industrial control components and industrial environments, so these industrial WCM's have become the benchmark technology around the world.

Each local control cabinet on the firing ramps contains a WCM. The WCM creates the connection from the PLC to the radio network. The WCM transmits all data sent from the PLC to the stationary network (backbone) via a corresponding wireless access point.

These wireless components require an industrial design for mounting inside the climate controlled electrical control panels as well as performing required functionality within an industrial automation system. Due to the daily fire move / crane handling, the equipment (especially for the ramps of the firing system) needs to be installed in accordance to industrial standards as an integral component of the firing control system, for example:

- Mountable on standard DIN rail
- Heavy duty / industrial power and signal connectors
- Suitable for industrial control voltage (24V DC) incl. standard allowable tolerances
- Vibration / shock resistant
- Suitable for industrial control panels
- Easy to troubleshoot, analyze and maintain.

Intelligent Control Modules

The design objective at BSL is to maximize the production performance and achieve this in parallel with cleaner baking cycles. For this purpose the anodes must be produced with:

- Low energy consumption
- Low emissions, and
- High consistency of heat treatment.

The following intelligent control modules have been implemented which ensure an on-line optimization of the process even under changing production conditions.

Oxygen Control by Flooding Index

With the on-line calculation of a Flooding Index [1] the actual oxygen levels in the firing area of the furnace can be evaluated, especially at the front burner ramp. Any lack of oxygen is automatically prevented via the Flooding Index Module as shown in Figure 5 by dynamic limitation of the burner capacity. Due to this module the system ensures a complete combustion of the gas fuel fed into the burners.

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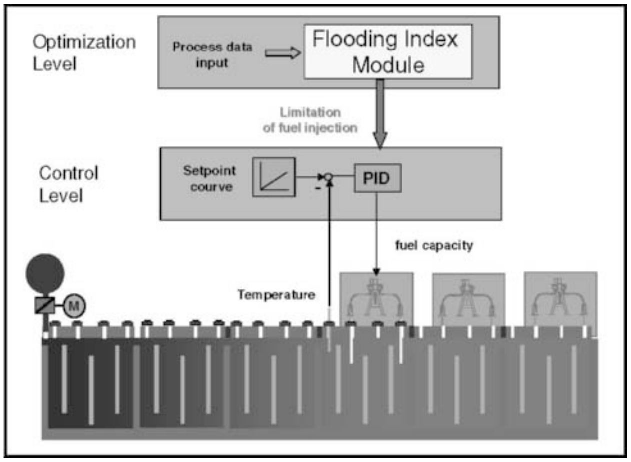

Figure 5: Flooding Index Module

Firing Index

Changes to the fuel input as a result of the flooding index module make it is necessary to leave the target baking curve temporarily. In order to ensure the same heat supply to all pits and thus a maximum consistency, the heat supply to the pits is recalculated by the Firing Index Module [1] and compensated by the control system as shown in Figure 6.

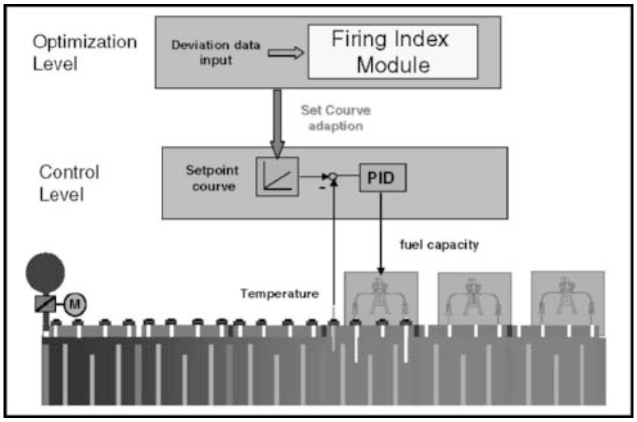

Figure 6: Firing Index Module

The Firing Index Module allows even greater deviations from the baking curve during the pitch burn phase. Here the burner capacity must be reduced in order to guarantee sufficient oxygen for the volatile combustion.

Pitch Burn Module

The Pitch Burn Module requires a specific recognition of the oxygen levels during the pitch burn phase. The Pitch Burn Module incorporates the opacity reading in the collection pipe of the exhaust ramp and the temperature gradients in the preheat sections, as illustrated in Figure 7.

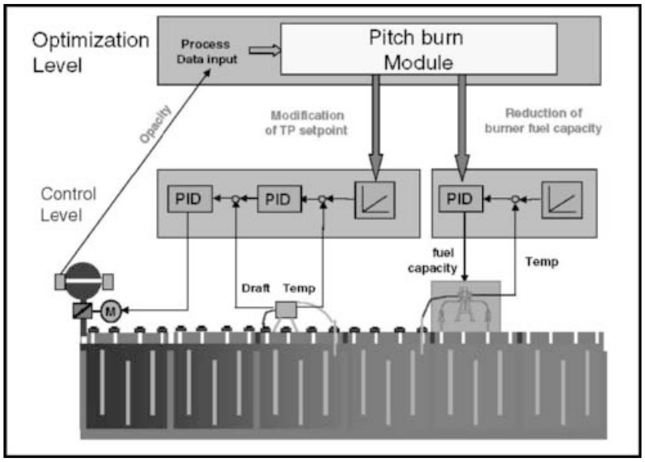

Figure 7: Pitch Burn Module

As a result of these observations the pitch burn module dynamically increases the draught (volume) in the individual flues and reduces the fuel gas consumption at the burner ramps in a two-step strategy.

Zero Point Control

The zero point control is also one of the essential technologies to minimize energy consumption and maximise the anode quality consistency. Therefore it utilizes one controlled blower ramp, a second “measurement” ramp for sensing the pressure behind the heating area and one uncontrolled cooling ramp. The furnace and equipment arrangement for zero point control is shown in Figure 8.

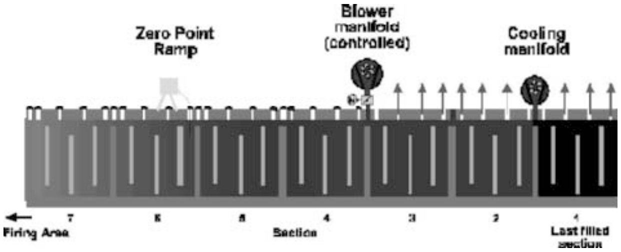

Figure 8: Cooling principle with “Zero Point” and controlled blower ramp

Between the last burner ramp and the controlled blower manifold all peepholes remain closed. So the cooling air can only leave the cooling area via the flue gas channels into the firing area. The preheated air enters the firing area and can be utilised for the firing/combustion process. For CBF4, the air volume of the blower manifold is produced from one central fan and controlled for each of the nine flues by individual motorized dampers to an accuracy of +/- 1Pa.

Since the flue gas volume that is necessary for the heat exchange process is normally larger than the necessary combustion air for the burners in the firing area, exclusively preheated air from the cooling area will be used for the combustion. This heat recuperation from the baked anodes is one of the largest contributors for the energy efficient operation of an open type anode baking furnace.

Precise control of the combustion air into the flues also minimises the potential for excess combustion of the packing coke in the pits. Too much pressurised air introduced into the flues can result in cooling air passing through the openings in the refractory walls and in coming in contact with the packing coke at temperatures above 650°C.

Results

Operational Safety and System Reliability

All existing baking furnaces at BSL have a hard-wired connection between each of the ramps of the fire group to connect the draught safety release signal. This system has been in use for many years and provides a high level of inherent safety to the fire control system due to the physical connection of equipment with a lead. The disadvantage is the need for leads to be placed across the floor of the furnace, and mechanical faults with the plugs and leads as the equipment ages.

For CBF4, a full wireless fire control system would not satisfy the AGA regulations. The design was adapted to incorporate a hard wired connection between the Measurement ramp and the Burner ramps. For BSL, the new design allowed the elimination of some plug and lead operational issues, while being compliant with the gas regulation.

The introduction of a wireless network communication between other ramps in the fire group was a new development for BSL. A second wireless network is in use for the CBF4 building, for communications from the furnace cranes. Testing of the strength and reliability of the fire control system network was performed with the cranes in operation and travelling to all areas of the furnace building to simulate all expected operating scenarios.

Gas Consumption and Off-Gas Emissions

Commissioning of the first fire group commenced in February and the fourth and final fire group was completed in mid April. By May, the furnace was fully operational and supplying all anodes previously supplied by the existing closed baking furnaces. Early gas consumption for the new furnace was in the range of 1.9 to 2.1 GJ/mt of baked anodes (Figure 9). Further opportunities have been identified to reduce consumption by tuning of the zero point and adjustment of the target temperature curves.

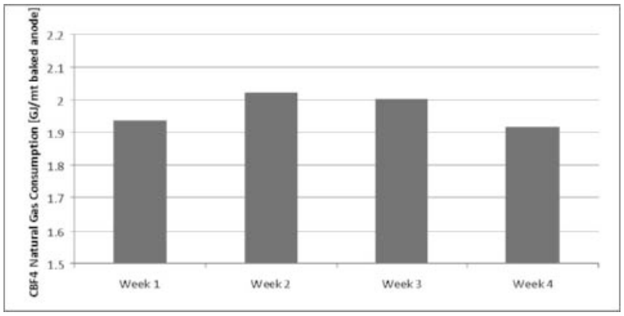

Figure 9: CBF4 natural gas consumption

Sampling of the off-gases from the furnace duct revealed low levels of volatile organic and polycyclic aromatic hydrocarbon (PAH) species, as well as carbon monoxide (CO), an effective indicator of pitch volatile combustion. Carbon monoxide readings (Figure 10) in the range 25-40 mg/Nm^3 were measured in the off gases during performance testing of the furnace and fume treatment centre.

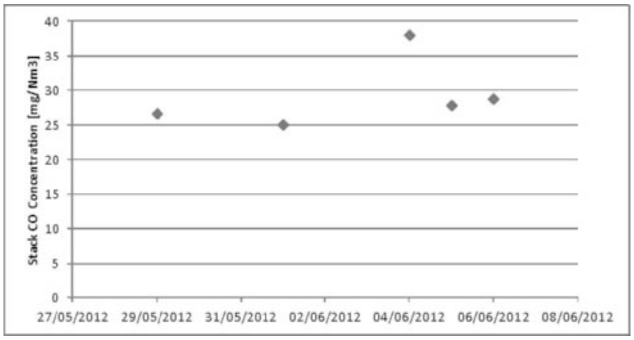

Figure 10: Carbon monoxide in the off-gases from CBF4

Selection of the target temperature curves for the new furnace was a key contributor to early achievement of the low natural gas consumption. In particular, the complete combustion of the pitch volatiles and the use of this heat energy in pre-heating the anodes is a key contributor to low overall natural gas consumption. The pre-heat target temperature curves were selected based on the collective experiences of the commissioning team, made up of Innovatherm, Rio Tinto Alcan, and BSL process engineers. Once the curves were selected, the advanced Intelligent Control modules of the firing control system allowed precise and repeatable control of the operating window around these target temperatures.

Anode Quality

For BSL, the goal with the CBF4 start up was to commission all four of the fire groups and achieve an acceptable initial baked anode quality in the shortest possible time frame. BSL were not able to sustain the operation of three furnaces due to pressure on green anode supply and manning, so it was important to have enough confidence in the early baked anode quality to shut down the existing closed furnaces.

A summary of the early anode quality data for CBF4 is given in Table I. At BSL, final anode temperatures and pit temperature profiles are assessed at using the equivalent temperature technique. A small crucible of green petroleum coke is placed in the stub hole of the anodes in the pits, and the crystal structure analysed after the baking process and converted into an equivalent temperature [2].

Table I – Early CBF4 furnace and anode property data. Standard deviation shown in brackets

Parameter	Units	Typical Value
Baking level	°E	1,225 (40)
Electrical resistivity	μΩ.m	57 (4.5)
Baked apparent density	kg/m^3	1560 (7)
CO_2 Reactivity Residue	%	94 (2)
CO in furnace off-gases	mg/Nm^3	25 – 40
Anode temperature at time of unload	°C	200 – 250
Natural gas consumption	GJ/mt baked anode	1.9 – 2.1

The early results from CBF4, along with a small scale trial of the anodes on the Reduction Line gave BSL the confidence to commence a rapid de-commissioning of the existing closed baking furnaces. Further, the initial results have given the plant process engineers a basis for further optimisation of the target temperature curves and burner set-up to reduce variation in temperatures within the pit and reduce the natural gas consumption.

Summary

This paper describes the results that can be achieved when a commissioning team comprised of experienced start-up and operations personnel is combined with a bake furnace fire control system with advanced process control functionality. It also demonstrates that the adoption of modern Wi-Fi communications technology and more stringent furnace safety requirements is no barrier to high system availability.

BSL has entered into a new era of anode baking capability, and is well prepared for the present and future challenges that will no doubt arise in the highly competitive aluminium smelting industry.

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