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ANODE BAKING PROCESS IMPROVEMENT AT ALRO

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Abstract

Along with the partial refractory refurbishment of their three anode baking furnaces, ALRO wanted to reduce their consumption of natural gas and achieve complete combustion of the volatile compounds. Fives Solios proposed its process control expertise and up-to-date technology to upgrade the existing Firing Control System. Advanced software along with CO analysers and high velocity gas injectors were implemented for better combustion control. Port Sealing Ramp and low pressure drop dampers were provided to improve the operating conditions of the furnaces. Additionally, baking profile adjustments, based on CO continuous measurement and balance between the draft and the thermal demand in the heating zones, were jointly conducted by ALRO and Fives Solios resulting in a sustainable reduction of the energy consumption and improved combustion of the volatile compounds while maintaining a consistent anode quality.

Project Background

ALRO group, the largest aluminum producer in Central and Eastern Europe has implemented a program of energy efficiency increase of its Romanian operations. The program implemented over the last six years aimed at lowering electricity, water and gas consumption and represents an investment of more than 40 million euro for the primary aluminum production.

In 2010, the investment focused on anode baking furnaces with the purpose of reducing gas consumption and preventing non-burned tar deposit in the exhaust ducts. In parallel to a program of refractory refurbishment, ALRO decided to upgrade the firing control technology operating since 2003.

The three 36 sections anode baking furnaces operating at ALRO, representing a total capacity of 150,000 tons per year, have been completely rebuilt from 2001 to 2003. In 2010, the average gas consumption reported was 2.56 GJ per ton of anodes. At this time, the percentage of flue walls rebuilt was less than 20% and the lifetime of the original flue walls achieved more than 90 turns.

Fives Solios was awarded the contract for Firing control system upgrade and process assistance. The project was divided in 3 phases, one for each furnace, with a first delivery within 4 months. The contractual target was to reduce gas consumption by at least 10%.

Preliminary audit

To identify current equipment status and furnace conditions, a preliminary audit was held on site in September 2010.

Audit conclusions focus on furnaces 1 and 4 because furnace 2 was shut down few months later for production adjustment.

Furnaces conditions

Both furnaces show a rather good global shape after 8 years of continuous operation, stating that maintenance is regularly brought. Similarly, we could not find out any major malfunctioning of firing control system, nor any improper running way of baking furnaces. But closer look on process parameters points out a lack of draught capacity at both furnaces sections mainly due to excessive pressure losses in main rings and flue walls.

The pressure losses are generated by the presence of tar in the main duct and by air ingress through refractory walls, mainly through head wall and flue wall interfaces. Exhaust draft pressure available at both furnaces sections is found very low with – 700 Pa only on average instead of -1400 Pa specified by the furnace technology supplier, despite FTC running at nominal capacity (-2000 Pa recorded at FTC inlet).

Figure 1 Overview of refractory conditions in furnace 4

Furnace 1 is characterized by a large deviation of available negative pressure from section 1 to section 18 and section 19 to section 36 indicating suspected high level of tar deposit in both ring ducts (600 Pa difference). The situation of the ring main is better for furnace 4 particularly for duct connecting section 1 to section 18 (300 Pa difference) but the maximum available negative pressure only reaches -750 Pa compared with -1000 Pa for furnace 1.

The average lifetime of refractory for furnace 4 is much higher than for furnace 1 and consequently gas consumption is higher in furnace 4 (flue walls replacement rate is only 7% on furnace 4 against 38% on furnace 1).

Status of the baking control

In the preheating zone, control system settings and running of controlling loops are as per expectations. But despite full requested opening of dampers, there is still a lack of air evidenced by lack of draft pressure at exhaust ramp (ER) as it can be read at the temperature and pressure measuring ramp (TPR).

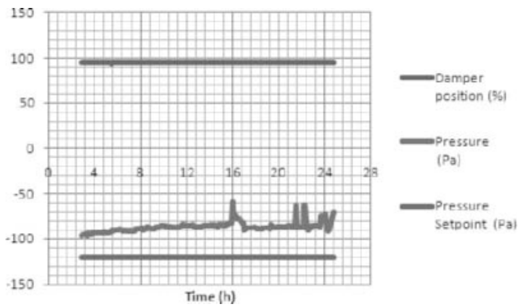

Figure 2 Example of pressure deviation in a flue wall of the preheating zone

Current baffles at rear part are assumed not to be air-sealed enough, that does keep gas temperature 150°C below expectation at TPR. Moreover, same baffles would not all leak in same proportions, as evidenced by discrepancies in draft pressure from one flue-wall to the next. That creates disturbance and lack of baking consistency. Moreover, to improve as much as possible the sealing the operator has to set manually plastic sheets on each gaps created by the brick misalignment, observed on ageing flue walls, against the mechanical gate side. This operation is time consuming and the end result is highly dependent of each operator skills.

Current fume connections between furnace and exhaust ramp are ensured by movable metallic fume ducts that were set a long time ago in place of initial flexible sleeves. These metallic ducts cannot be properly air-sealed. It leads to detrimental fresh air ingress and great heterogeneity in pressure profile from one flue-wall to the next.

In the heating zone of both furnaces, although set points are timely and properly addressed, all injectors of the first and the second heating ramp are running at the maximum power authorised, but gas temperature remains below expectation with no more margins to act on. The main explanation is that in this flue wall area there is a lack of oxygen to burn properly the injected gas.

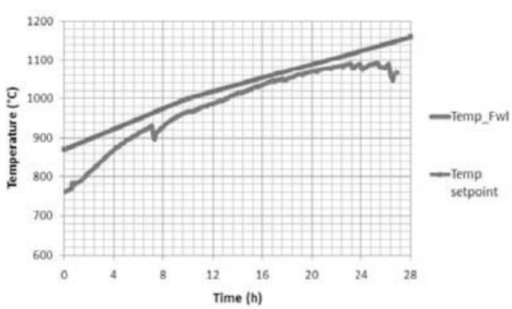

Figure 3 Example of temperature deviation in a flue wall of the heating zone

In the Blowing zone, the operating conditions are found acceptable with all settings under control.

Corrective actions

After the preliminary audit, the following action plan have been settled by Fives Solios and agreed by ALRO. It includes:

- Actions to increase the draft available for each flue wall line,
- Actions to improve the combustion quality,
- Upgrade of the firing control system with up to date technology for process and combustion control followed by training of the process engineers and operators.
- Process tuning by Fives Solios in collaboration with ALRO specialists.

Even if the equipment were well maintained, some mandatory actions were found to be delayed. Great efforts have been made to bring the equipment to their nominal state:

- Damage cables and electrical boxes were changed,
- All damper motors were checked,
- All pressure transmitters calibration were checked,
- Exhaust ramps were cleaned and painted,

As it was not possible to increase the available draft in the main ring to an acceptable level by increasing the capacity or setpoint of the FTC, corrective actions were taken on the furnace and on the equipment to minimize the loss and to take full advantage of the draft available at the main ring to go back to acceptable pressure profile all across the furnaces:

The first actions consisted in maintenance works on the furnaces:

- All the damaged peephole covers were replaced by new peephole cover with seal and insulation in the middle in order to limit air ingress and heat loss while facilitating their handling by the operators.
- All unused main ring connections were properly air-sealed with new rubber sheet at least 200 mm larger than the main ring cover diameter when it was necessary.
- All Temperature and Pressure Ramp, Zero Point Ramp and Heating ramp pressure intake or thermocouple covers were checked and replaced by new ones if necessary.
- All heating ramps peephole covers were changed for cast iron covers internally coated with insulating concrete. These covers were equipped with seals as it was decided not to put back the cast rings on the flue-wall peep holes.
- Furnace refractory status: Some port were found damaged (section restriction) and some flue wall were found blocked by coke or refractory. The long term refractory maintenance plan has been updated accordingly in order to give priority to the defective walls.

To increase the available draught, , new supplies, associated to latest process control achievements have been proposed:

- New flexible ducts on ER in place of existing metallic fume ducts: these new sleeves have been demonstrated to be high temperature resistant with inner stiffeners.
- Dual flap dampers to be installed on ER: Benefits are both on process and maintenance sides, namely with:
  - Less pressure drop, to save maximum of draft available, for combustion,
  - Concept less likely subject to fouling with tars.
  - Easier to maintain as they can be dismounted without tools thanks to quick couplings.

Figure 4 Flexible exhaust leg with dual flap damper

- Adding of latest Port Sealing Ramp (PSR). The PSR is equipped with air-blown patented inflatable sealing membranes. The proposed inflatable shut-off gates offer better results related to the tightness compared to the conventional folding shut-off gates (expandable dampers) because the inflatable membrane perfectly fits the ageing flue wall port inner surface [(2)].

Figure 5 PSR inflatable membrane sealing a port

All the improvements that had been brought recently by Fives Solios on the combustion side have been installed:

- The last generation of gas injectors. This new injector is designed to provide high velocity of combustible promoting mixing with combustive air and combustion reactants. The aspiration of non-reactive mass into the main gas jet has a beneficial effect on flame length and peak flame temperature and consequently improves the thermal distribution inside the flue wall.
- The last version of the control software including the following process algorithms:
  - "CO monitoring" module: This patented solution uses Carbon Monoxide measurement as indicator of incomplete gas and pitch combustion to prevent from non-burned volatiles to appear and build up. The attached monitoring function makes it reacting automatically, through process control, on blowing & heating parameters.

Figure 6 CO analyzer in position on Exhaust Ramp

  - "Pitch burning" system: Using a three steps automatic control strategy for the pre-heating zone, this advanced feature will insure that the pitch volatiles combustion is complete while maintaining the anode heat-up rate within a preset range.
  - "Anti-Flooding" protection, which is a specific function combining concepts of thermal gradient limitation and splitting of maximum authorized fuel power over the three heating ramps.
  - "Crossover" management: this function alleviates the impact of unavoidable mix of circulating gas (fumes) at cross over location on downstream flue walls.
  - "Ramp recovery" system, which is a specific function to achieve a smooth start-up of the heating ramps after the fire permutation by assessing the temperature of the flue wall before to restart gas injection.

Along with improvements brought to combustion, the control software package has been upgraded with the new supervision and data management solutions including new user interfaces with enhanced data access and analysis. The upgrade of the centralized control software was implemented without any major modification at the PLC level.

Baking process optimisation

Following the work of firing equipment revamping and control system upgrade, efforts focused on the optimization of the baking process. The strategy for improving baking conditions was deployed in two phases:

- A first phase of setting the firing curve to reach optimal overall system performance in the standard operation condition of the furnace.
- A second phase of activation of the CO monitoring module to automatically adjust the gas quantity injected according to the air available in the flue wall where standard conditions are not reachable

Setting the firing curve is an important and delicate operation that must improve the thermal efficiency and the quality of combustion in the furnace without degrading the quality of the anodes. The temperature programs were originally set in 2003 after the renovation of the baking furnaces.

The adjustment of the firing parameters was carried out by comparing the thermal gradients in the preheating and heating zones coupled with the observation of average levels of carbon monoxide in order to balance the air to fuel ratio.

In the preheating sections draft pressure, as well as fume flow, is influenced by the temperature profile. This means that the flow of flue gases flowing along a flue wall line depends strongly on the temperature settings of the preheating zone.

Considering equivalent conditions in the baking furnace (gas temperature, the pitch degassing intensity, amount of gas injected, air ingress), the heat flux exchanged by convection between the hot gases and refractory walls increases with the gas velocity, and therefore in an equal cross section, with the fumes flow.

The following empirical formula illustrates this aspect of the convective heat transfer:

$Q=23.46 \times A \times DT \times V^{0.78} \times d$ (1)

With

Q = Heat exchanged (kJ/h)
A = Thermal exchange area (m²)
DT = Temperature difference between fumes and flue walls (°C)
V = Fumes speed (m/s)
d = Fumes density (kg/m^3)

At equivalent conditions, this additional energy will generate by convection and conduction a proportional elevation of the temperature of the refractory walls and of the anodes. As a result, the thermal gradient measured in the preheating zone varies proportionally with the volumetric fumes flow to the power 0,78th:

$\Delta T=\alpha_{ref} * Qv^{0.78} \Rightarrow Q_v \sim \Delta T^{1/0.78}$

With α_{ref}, a constant equal to $\Delta T_{ref}/(Qv_{ref})^{0.78}$

In the heated sections, the temperatures of the fume gases and the flue walls are established according to the quantity of gas injected. The baking furnace control is performed by measuring the temperature of fumes and adjusting the amount of gas injected in order to obtain a fume temperature as close as possible to a target temperature.
In this zone, the temperature gradient is proportional to the quantity of gas injected.

$Q=Q_{gaz} \times PCI_{gaz}=mC_p\Delta T \Rightarrow Q_{gaz} \sim \Delta T$

In the intermediate sections, a portion of the pitch content in the anode is volatilized and acts as a fuel providing 50% of the energy required for the process of baking. Taking into account the amount of pitch volatiles degassed is therefore necessary to study the stoichiometry balance in a flue wall. The intensity of the degasing phenomena during a baking cycle operates as a bimodal Gaussian distribution with an area equivalent to the energy injected in the heating zone and a dispersion σ equivalent to the baking cycle time divided by 8. The discrete form of this curve allows deducting the equivalent amount of gas corresponding to the pitch volatiles evolved. These amounts will be added to the amount of gas injected in the same period.

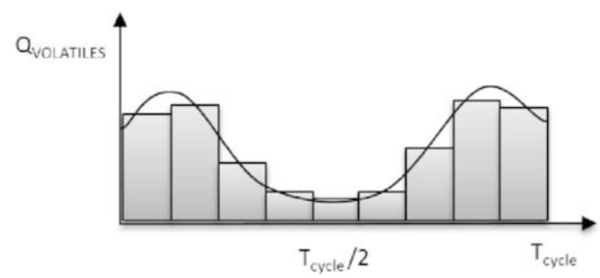

Figure 7 Quantity of volatiles evolved during a baking cycle

Thus, balancing the thermal demand between the preheating and heating zones amounts to balance the ratio between the fuel (gas injected + volatiles) and the combustive air in a flue wall line.

In practice, we conducted a superposition of the thermal gradient of the preheating zone (to the power 1/0.78) and the temperature gradient resulting from the first and the second section of the heating zone. We do not consider the last section of the heating zone, because it is less influenced by the exhaust draught and because the temperature gradient is typically null in this area (soaking temperature). The following ratio is plotted as a function of time during a baking cycle:

$R_{(HR/ER)}=[Grad(T4)+Grad(T5)]/[Grad(T1)^{1/0.78}]$

We also plot the ratio between volatiles quantity and fumes flow during a baking cycle:

$R_{(VOL/ER)}=[Qvolatiles]/[Grad(T1)^{1/0.78}]$

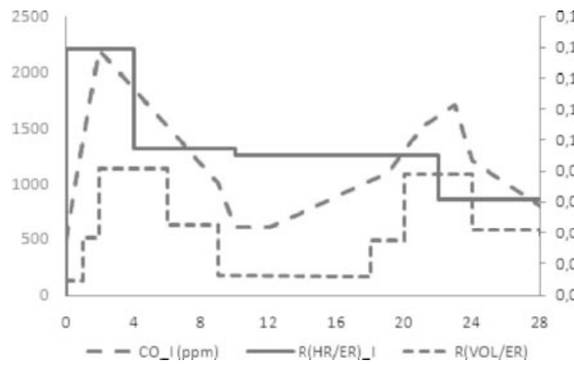

Figure 8 Fuel and volatiles to air ratios deducted from initial baking program

By superimposing the 2 ratios, we obtain the global fuel to air ratio in a flue wall line along a baking cycle, $R_{(HR+VOL/ER)}$. It is remarkable that this ratio is perfectly correlated with the level of CO recorded by the in-situ analyzer.

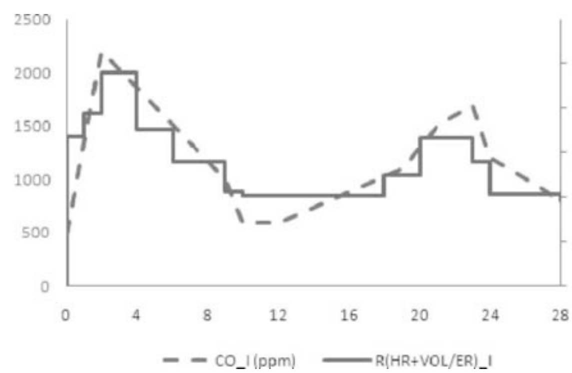

Figure 9 Fuel to air Ratio from initial baking program

From the analysis of the fuel to air ratio and the level of CO, it is easy to identify areas in the baking cycle where the process stands under stoichiometry balance. We see that especially in the early hours of the heating cycle, the heat demand in the area of the forced heating zone is excessive, generating a peak of CO greater than 2000 ppm.

Adjusting the thermal gradients in the exhaust and heating zones amounts to balance the ratio between draught (air available) and thermal demand in the heating zone (amount of fuel injected) along the cycle.

Note that changes in the baking programs were performed within the limits of permissible thermal gradient, especially in the preheating zone with regards to anode quality.

The new baking curve profile obtained following this method showed immediate results in combustion quality improvement. For the same sections of the baking furnace operating in the same conditions, the average value of CO level recorded along one baking cycle decreased from 1100 to 700 ppm (see curves CO_I and CO_M in Figure x)

The implementation of the new firing programs was done with a closed follow-up of the baked anode quality by ALRO process engineers. The anode baking level and temperature homogeneity remained stable. The main properties used to qualify the baked anode and in particular the resistivity parameter highly dependent on the baking level remains identical before and after modification of the program.

	Density (g/cm3)	Compressive Strength (Mpa)	Elasticity (Gpa)	Resistivity (μΩ.cm)	CO2 residue	O2 residue (%)
Curve_I	1,61	46,1	5,1	5157	82	68,3
Curve_M	1,60	44,1	5,3	5149	80	68,9
				Target <5200		

Table 1 Anode quality comparison

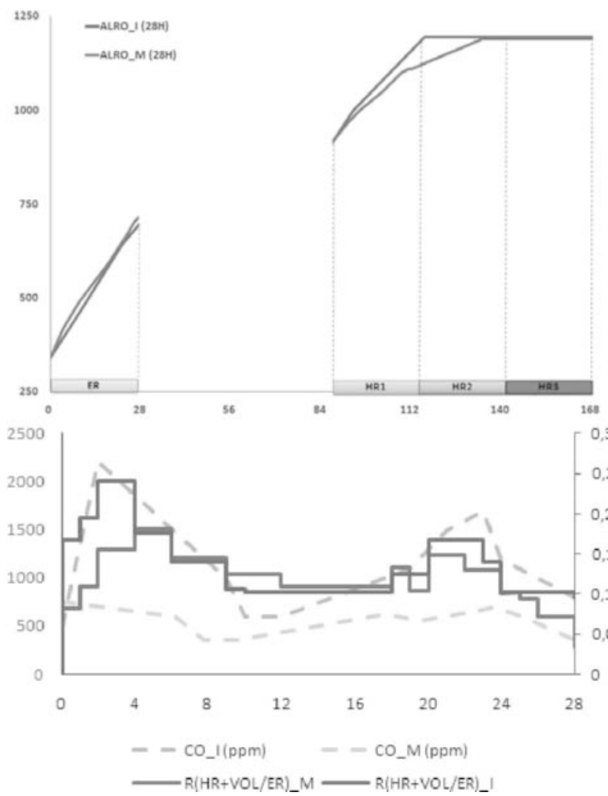

Figure 10 Initial ("I") and modified ("M") baking programs comparison

In parallel of the global adjustment of the baking program based on thermal gradient balance between preheating and heating zones, the automatic control module, dedicated to the reduction of non-burned residue and included in the new control software proposed by Fives Solios was activated in order to overcome the problems of combustion in bended or blocked flue walls. We remind that during the revamping project, the percentage of flue walls rebuilt was less than 20% and the lifetime of the original flue walls achieved more than 90 turns

The CO monitoring module, coupled with a CO analyser per fire is able to display the real time CO content and alert the operator when incomplete combustion situation appears. It is equipped with an automatic flue wall identification which is able to detect the flue wall(s) in bad combustion situation.

In case of fuel flooding, fume flow disturbance, shifted pitch volatile area or other baking deviation phenomena leading to high CO content in the exhausted fumes, the CO monitoring module automatically searches for the responsible flue wall and manages the appropriate actions through the process control system by moderating fuel quantity injected or by increasing the volume of blown air within predefined limits in order to maintain baking quality.

The innovative method of identification is based on CO content comparison after the total fuel injection stoppage during a short period for the pre-selected flue walls upon stoichiometry criteria. This method is safe as it is a comparison by default (fuel injection stoppage instead of excess fuel injection). It is also "non destructive" for the process as it is applied for a very short time period thanks to CO measure accuracy and fast response time.

The CO module has shown its great capability to firstly identify the flue wall line in bad combustion and secondly to reduce the global CO content and consequently the unburned residue emission.

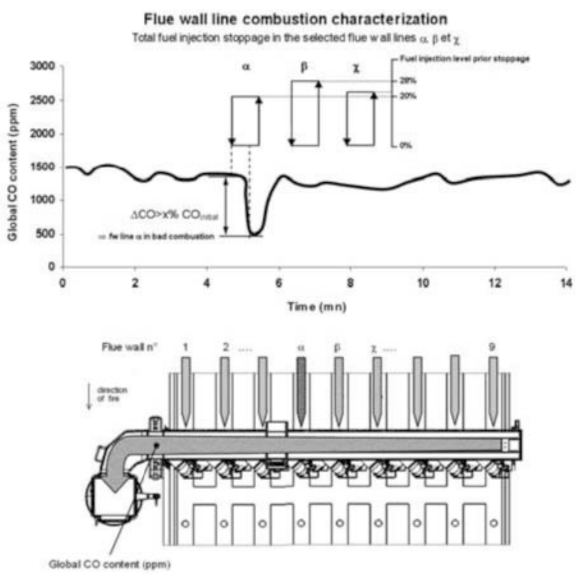

Figure 11 Principle of combustion characterization by the CO control software module

Following the baking program adjustment and the CO monitoring software activation, a decrease of more than 30% of the CO content in the fume was recorded, reflecting a major improvement of the combustion quality and thermal efficiency of the baking process.

Sustainable improvement

Thanks to the following solutions implemented at ALRO during the upgrade of the firing control system, sustainable improvement has been recorded at both furnaces in operation:

- Improvement of exhaust draft in the flue walls thanks to PSR and low pressure drop dampers
- Baking program adjustment according to thermal gradient and CO level
- Automatic correction of local combustion problems thanks to CO module
- Gas mixing improvement thanks to high velocity burner technology

The major improvement of baking process quality is the result of the baking curve adjustment, the implementation of the automatic combustion control module dedicated to bad condition flue walls as well as the increase of draught capacity thanks to new sealing solution.

Improving combustion quality, which corresponds to an optimization of the overall thermal efficiency allowed achieving and exceeding the contractual performance. The natural gas consumption achieved 2.11 GJ/tba in baking furnace n°1 and 2.24 GJ/tba in furnace n°4, resulting a decrease of energy consumption by more than 15%.

Reducing combustion residue also represents an indirect cost saving thanks to lower equipment cleaning and maintenance requirements, thanks to the reduction of the risk linked with the deposition of pitch in the exhaust pipes and thanks to the increase of furnace refractories lifetime (corrosion of refractory material by alkalis is typically accelerated in reducing atmosphere).

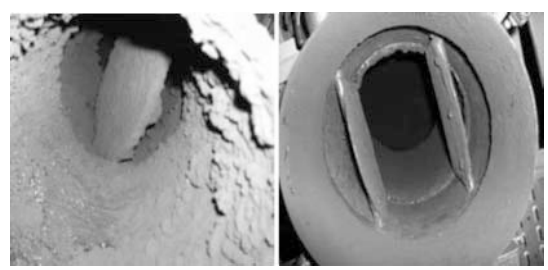

Figure 12 Combustion residues in exhaust pipe before and after upgrade

18 months after the implementation of the revamping solutions, the performances remain stable at ALRO baking furnaces with an average gas consumption less than 2.2 GJ/tba. The non-burned residue and tar deposits are significantly decreased.

The new equipment proposed, and particularly the PSR inflatable membranes show a great resistance to process conditions on continous operation with an average lifetime higher than 6 months.

Conclusion

Improving anode baking process efficiency and operation conditions in ageing furnaces is a challenge for carbon producers. Except the refurbishment of flue wall refractory, the key factor for such improvement is the combustion quality. Balancing fuel to air ratio requires improving draught capacity, balancing thermal demand between both preheating and heating zones and limiting fuel injection where air cannot be provided. This challenge was met at ALRO thanks to the implementation of the following innovative solutions:

- Inflatable port sealing to limit air ingress
- Baking profile adjustment with a new method of balancing thermal gradients between heating and preheating zones
- Automatic control of carbon monoxide content in poor condition flue walls

The improvements recorded do not only concern natural gas consumption decrease but also non-burned residue limitation, maintenance operation reduction as well as refractory bricks lifetime extension.

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