

NO_x Emission Reduction in Kiln-5 at ALBA (Aluminium Bahrain)

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Abstract

The anode baking process is highly energy-intensive, requiring approximately 2 GJ/t of baked anodes. In this process, refractory walls are heated by direct gas injection from the top of the furnace to bake the anodes. However, combustion emissions, particularly nitrogen oxides (NO_x), have become a significant concern in industries that rely on fossil fuels. NO_x generation in kilns results from a combination of thermal NO_x, fuel NO_x, and pitch volatiles combustion efficiency. Thermal NO_x are formed during combustion of gas and air mixture at high baking temperatures (> 1 170 °C) inside the flue. ALBA Kiln-5 had been experiencing high NO_x levels (> 250 mg/Nm³) since its inception, which was a major issue. Under the Environmental, Social, and Governance (ESG) initiative, reducing NO_x emissions was a top priority for ALBA. This paper presents the experiences of ALBA in successfully reducing NO_x emissions from >250 mg/Nm³ to below 100 mg/Nm³ consistently. This achievement was made possible through various in-house trials and optimization of baking parameters, and the installation of ultra-low NO_x burner nozzles in all fire groups. The introduction of specially designed low NO_x burner nozzles resulted in a significant reduction in NO_x emissions without compromising the baking process, anode quality, or thermal homogeneity inside the flue wall.

Keywords: Carbon anodes, Baking kiln, Thermal NO_x, Low NO_x burners, Fuel combustion.

1. Introduction

Aluminum Bahrain (ALBA), is the world's largest single-site aluminum smelter outside of China, with an annual aluminum production capacity of over 1.6 million tonnes, is renowned for its technological advancement and innovative strategies. ALBA's Kiln 5 was commissioned in 2019 as part of the ALBA's Line 6 project. This kiln consists of 68 sections and 4 fire groups, operating on a nominal fire cycle of 24 hours. Waste gases are treated with alumina in the Fume Treatment Centre (FTC) to reduce fluorides and other contaminants, and clean gases are released into the environment via the stack. The FTC is equipped with three Induced Draft fans to create adequate draft to run the fires, a cooling tower to cool down the gases, 8 bag filters, and silos for fresh and treated alumina. The nominal gas flow to Kiln-5 FTC is 115 000 Nm³/h. Natural gas is used as fuel and is injected into the flue walls through burner nozzles installed on burner ramps to achieve anode baking level (Lc) close to 34 Å.

2. NO_x Emission at ALBA Kiln-5

NO_x has a detrimental impact on both human health and the environment, causing respiratory diseases and contributing to the formation of acid rain when it reacts with the atmosphere. Since

inception, Kiln-5 NO_x emissions from the FTC stack were in the range of 280–300 mg/Nm³ (Figure 1). In 2023, ALBA management decided as part of environmental continuous improvements to reduce the NO_x emissions limit to 150 mg/Nm³.

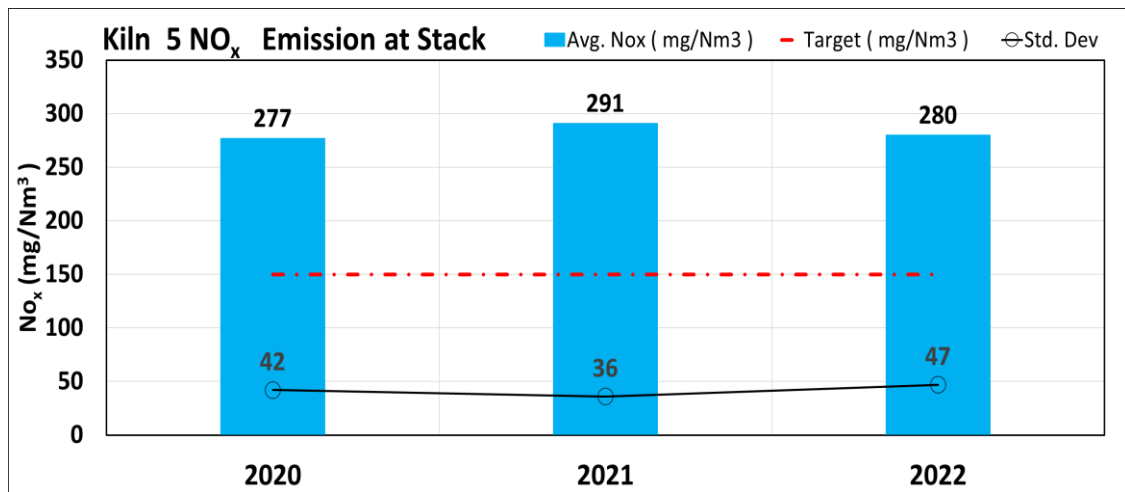


Figure 1. NO_x emission from kiln 5 (blue) and target (red).

In kilns NO_x generation is a result of a combination of thermal NO_x, fuel NO_x, and pitch volatiles combustion efficiency. Nitrogen oxides (NO_x) are primarily generated by the firing control system, and there is no simple method to reduce them at the stack level. Therefore, NO_x formation to be reduced at source to reduce stack emission.

3. NO_x Reduction by Process Optimization (Initial Trials)

Thermal NO_x is formed at high flame temperature combined with high air concentration. Initial trials were done to reduce thermal NO_x formation during firing, by optimization of process parameters and fine tuning of gas injection into the flue walls:

- Burner pulse duration was increased from 0.4 s to 1.2 s to increase flame volume and reduce heat flux density.
- The fuel gas nozzle tip was retracted from 30 mm to 50 mm away from the burner tip to reduce average velocity of the fuel gas jet to reduce flame peak temperature.
- Improved sealing of the burner nozzle by inserting ceramic wool between nozzle base plate and the top of the peep hole cover to prevent air ingress during pulsing.

After implementing above changes in the firing system, the average NO_x content measured at the FTC stack was reduced from 282 to 252 mg/Nm³ (Figure 2). However, the target value of 150 mg/Nm³ was not achieved. Another trial was conducted by reducing gas peak temperature by 10 °C, NO_x emission reduced slightly but baking level dropped significantly, so trial was reverted immediately. ALBA objective was to reduce NO_x emissions below local legal limits without compromising on anode quality and performance in pot rooms.

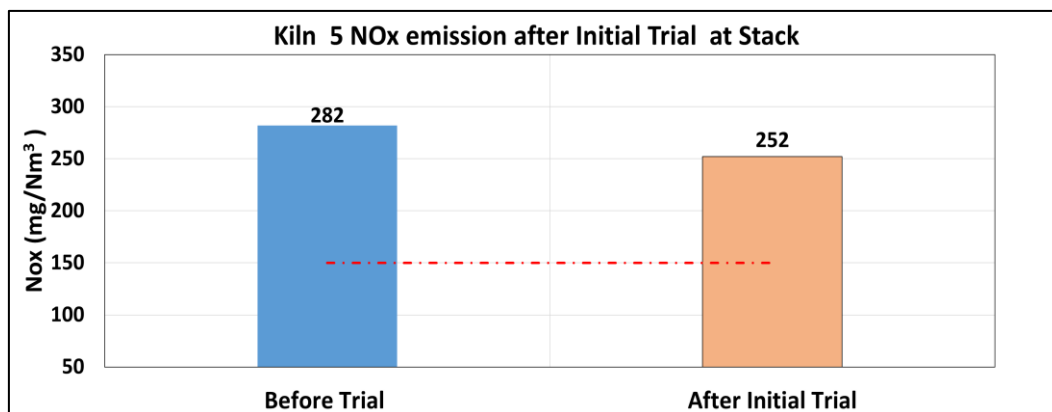


Figure 2. Kiln 5 NOx emission at stack after initial trial.

4. Introduction of New Generation Low NOx Burners Nozzles

After literature research review [1] and discussion with other technology providers/supplier ALBA came across specially designed new generation burner nozzles those could help to reduce NOx emission without compromising on baking process, anode quality and flue walls. ALBA decided to conduct trial with new generation burner nozzles. ALBA's strategy to replace existing burner nozzles with new design burner nozzles to reduce NOx was based on the following evaluation criteria:

- Consistent low NOx levels ($< 150 \text{ mg/Nm}^3$), regardless of fire cycle, draft conditions, etc.
- Maintaining baking level ($L_c > 34 \text{ \AA}$) with good baking homogeneity inside the flue.
- Maintaining Refractory flue wall brick temperature at same level.
- Optimum fuel gas consumption.
- Good operational life and repair cost of the nozzle.

The replacement of existing burner nozzles with specially designed low NOx burner nozzles was carried out in three phases to ensure a smooth transition with minimal or no impact on kiln process, anode quality, and flue wall life.

4.1 Phase 1: Preliminary Data Collection

In this phase preliminary collection of information allowing the sizing of the injectors and the validation of the guaranteed NOx emission value after the installation of the injectors were done.

The following parameters were collected/validated in kiln 5 fire groups, whose arrangement is shown in Figure 3:

- Flue wall dimensions and fire group PID parameter setting, gas flow rate and pressure, injection capacity of the burners 1, 2 and 3.
- Last one year anode baking level (L_c).
- Baking program to evaluate NOx emission on different fire cycle ages.
- Burner nozzle configuration and interface connection between gas pipe and existing burners nozzle, size of the peep hole cover diameter of the hole, etc.
- Refractory temperature.
- Gas consumption.

NOx emission level was checked at each exhaust ramps and FTC stack. Average NOx emissions level at exhaust ramp was 267 mg/Nm^3 and at FTC stack was 282 mg/Nm^3 .

With this phase base line of the NO_x emission level was established and its help supplier to develop the new generation burners nozzle customized as per ALBA requirements.

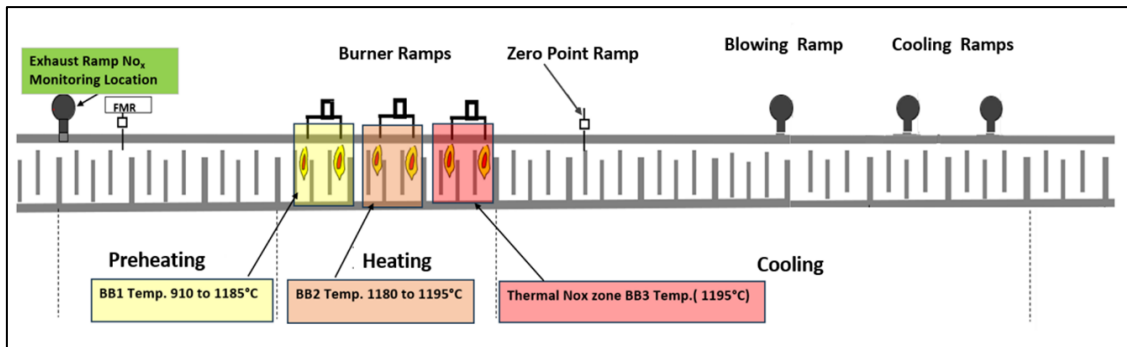


Figure 3. Kiln 5 fire group arrangement and NO_x monitoring location.

4.2 Phase 2: Installation of New Burners (Figure 4) in One Fire

New burners nozzle was installed in one fire group (trial fire), while the other three fires remained with old burners (normal fire). A total of 54 burners were installed with the same setup, with no change in the gas hose line connection design. Peep hole cover was used with increased height (from 50 to 85 mm) to protect the nozzle from heat exposure. The new nozzle height under the base plate was also 85 mm.

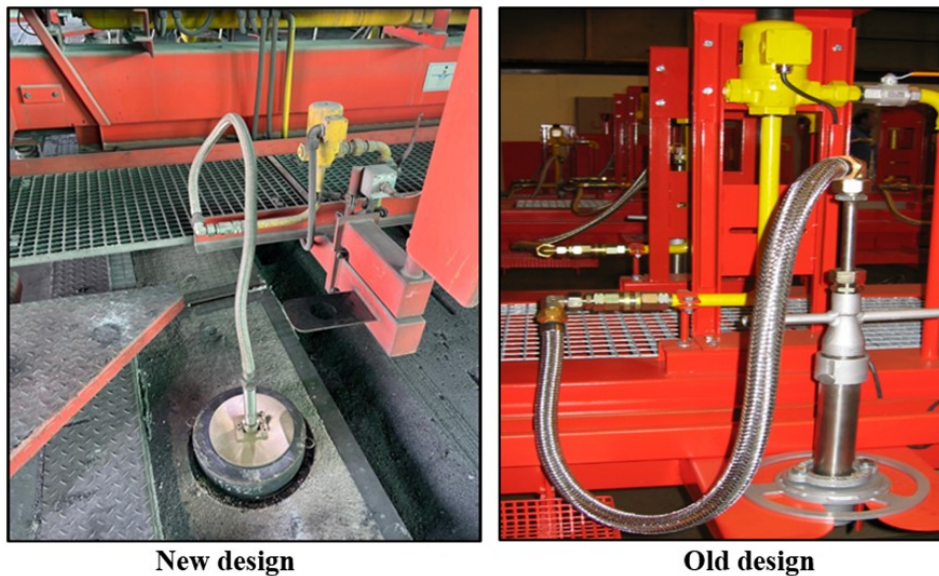


Figure 4. Kiln 5 burners.

The performance of the trial fire group with special design burner nozzles was evaluated over a nine-month period and compared to the other three normal fire group. The results showed a significant reduction in NO_x emissions at the exhaust ramp of the trial fire, with a decrease of almost 50 % (Figure 5). Moreover, the variation in NO_x emissions also reduced. NO_x values remained reliable, consistent, and stable over the nine-month period in trial fire group.

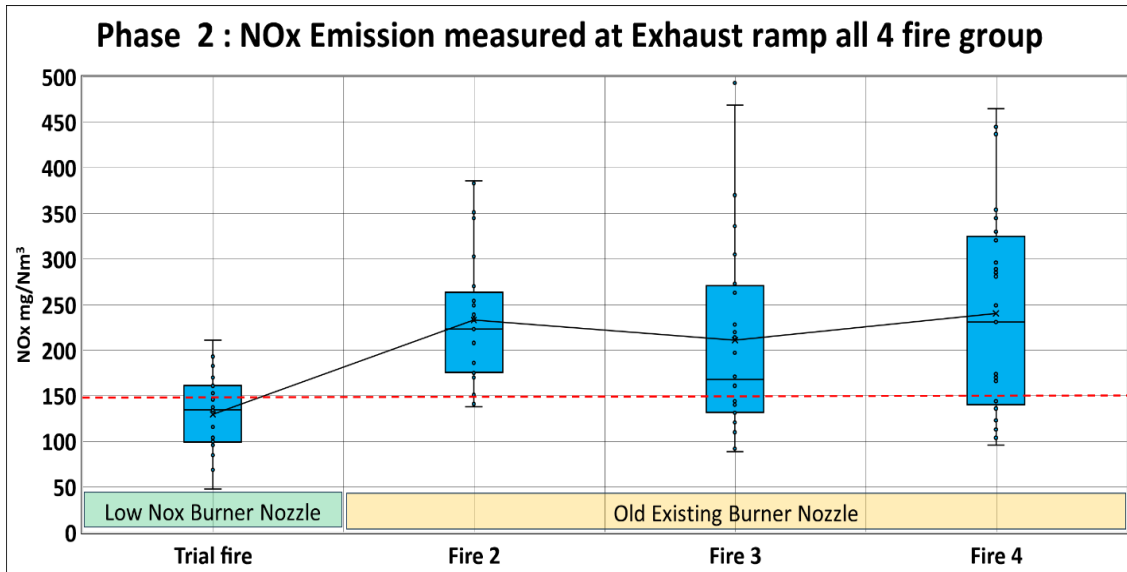


Figure 5. Phase 2: NOx Variation in trial and normal fire groups.

Kiln 5 stack emission also reduced by 25–30 % as shown in Figure 6.

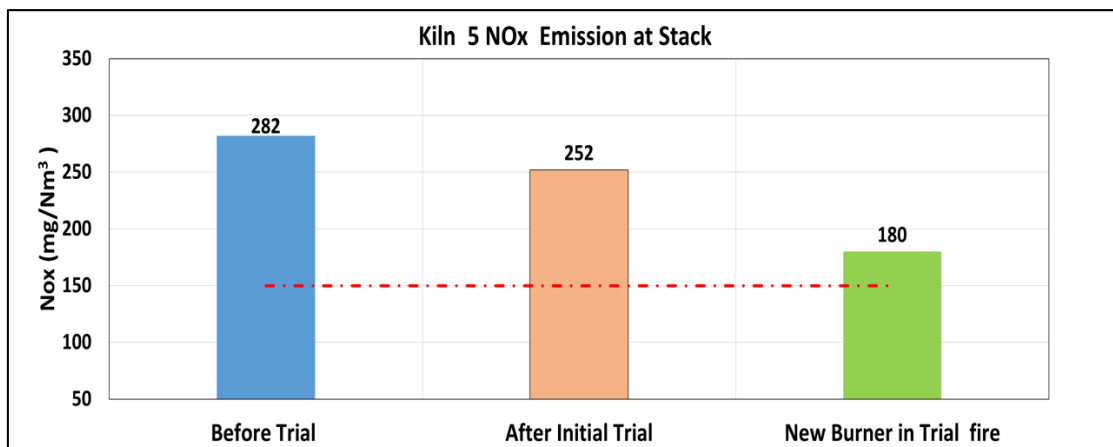


Figure 6. Kiln 5 NOx emission after installing new burner nozzles in one fire group.

Anodes core samples were taken from trial fire and baking level of anodes (Lc) other parameters were analyzed. Anode baking level was well maintained in target range with same level of variation (Figure 7). Refractory flue wall brick temperatures were measured at several location and found same as with old burner nozzles. The maximum refractory temperature was 1 370 °C with no sign of hot spots. With new generation burner nozzles target baking curves were well achieved with complete pitch burn.

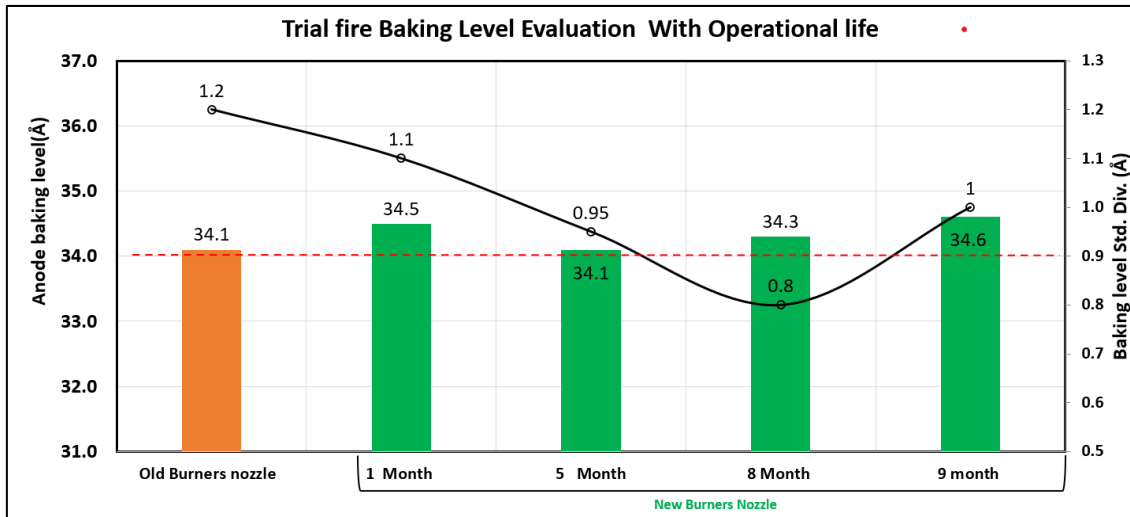


Figure 7. Kiln 5 Anode Baking level after installing new burner nozzles in one fire group.

Regular inspections of the nozzle's physical condition revealed that over a period, the low NOx emissions burners nozzle began to wear out (Figure 8). Nozzles exhibited some wear at the bottom part of the injector after six months, which was replaced with spare new wear part available. The length of the nozzle decreased but had no impact on process. Some efforts to protect and improve life of wear part of low NOx nozzles are ongoing.



Figure 8. Burner nozzle condition after 9 months of Service.

4.3 Phase 3: Installation of New Burners Nozzle in All Fire Groups

Following the successful demonstration of the low NOx burners nozzle performance and their impact on the baking level of the anodes for nine months on trial fire group, ALBA decided to replace the old burner nozzle in other remaining fire groups with new generation low NOx burners nozzles. The installation was done in each burner ramps during scheduled preventive maintenance. Once all fire groups were equipped with the new nozzles, daily NOx monitoring was conducted on FTC stack, and a significant and consistent reduction in NOx emissions was achieved, with a level of below 100 mg/Nm³ (Figure 9).

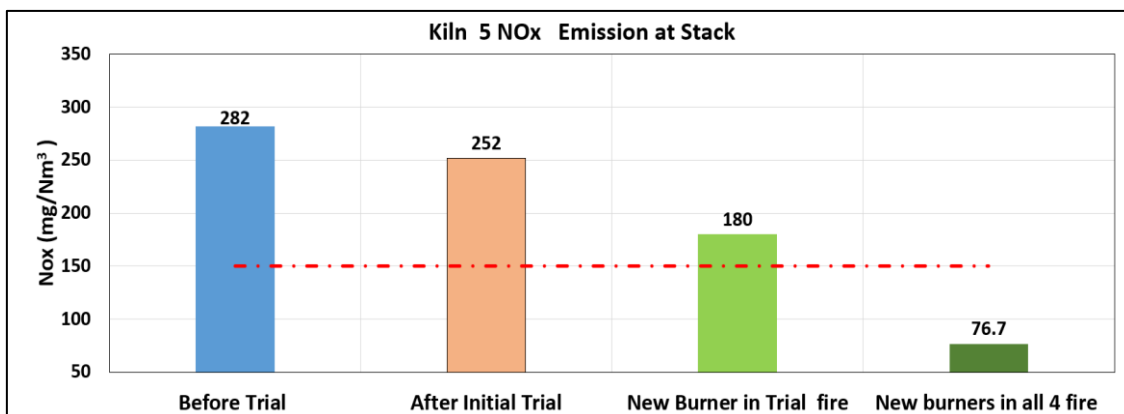


Figure 9. Kiln 5 NOx Emission at stack.

5. Results and Discussion

Initially, efforts to reduce NOx emissions level was focused on optimizing fire parameters such as fuel-to-air ratio, combustion temperature, and residence time, as well as making mechanical adjustments to the burners such as modifying the burner nozzle design and fuel injection pattern. 10 % reduction in NOx levels was observed with initial trial. With use of new generation specially designed burner nozzles a significant reduction in NOx emissions was achieved. NOx level reduced by 70 % from 252 mg/Nm³ to 76.7 mg/Nm³ which is well below to the new legal limit of NOx emission.

The new burners nozzle featured a proprietary nozzle design that improved fuel atomization, mixing, and combustion efficiency, leading to:

1. Homogeneous temperature distribution along the flue wall, resulting reduced thermal NOx formation.
2. Optimizing oxygen concentration in the combustion zone, thereby reducing the formation of thermal NOx.

The gas jet configuration played a crucial role in NOx formation, as it influenced the local mixing rate of fuel and air, which in turn affected flame temperature and its stability. With new burners nozzle a large volume of the flame temperature homogeneity was obtained. As volume of flame increases the heat flux density resulting in reduction of flame peak temperature. This reduces formation of NOx during combustion process and later reduce NOx emission at the exhaust ramp and stack.

Overall, the specially designed burners nozzle helped to achieve a significant reduction in NOx emissions, maintaining efficient and stable combustion, baking homogeneity, flue wall temperature distribution and gas consumption.

Table 1. NOx reduction project summary: KPI Evaluation.

Parameter /observation	Before NOx Reduction Project	After NOx Reduction Project
NOx Emission level (mg/Nm ³)	250–300 (Std.Dev. 39)	75 (Std.Dev. 18)
Burer's nozzle service life (Month)	9	9
Baking process	Stable, complete pitch burn	Stable, complete pitch burn
Anode Baking Level(Å)	> 34 (Std.Dev. 1.1)	> 34 (Std.Dev. 0.9)
Refractory temperature (°C)	93 % reading < 1 370 °C, No hot spot	96 % reading < 1 370 °C, No hot spot
Gas Consumption (GJ/t BA)	1.80	1.75

6. Conclusions

To comply with the new stringent environmental regulations, ALBA has adopted latest low NOx burners nozzle technology. NOx emission from stack reduced by two thirds with the implementation of new generation burner nozzles and fine tuning of process. With the successful completion of the NOx reduction project, ALBA has set a precedent by demonstrating its commitment to environmental protection, a key ESG goal. The kiln operation is now running smoothly and safely with the new burners. ALBA achieved reduction in NOx emission below local stringent emission limits with no negative impact on baking process, anode quality, flue wall life and gas consumption.

7. References

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2. Pierre Mahieu, Patrice Sedmak, Improving fuel gas injection in anode baking furnace, *Light Metals* 2014, 1165-1169.