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MODERN REHEATING PRACTICES FOCUS ON COMBUSTION TECHNOLOGY[1]

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Abstract

This lecture introduces combustion systems and controls as one of the most important features in the design of modern reheating furnaces, starting with a general overview of the available technologies, their development in the years and the actual State of the Art.

Key words: Reheating furnaces; Combustion; Technology; Energy efficient; NOx emission; Flameless burner.

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1 INTRODUCTION

1.1 Latest Walking Beam Furnaces enhancements

The latest Walking Beam Furnaces enhancements can be listed as:

- Skid marks <10 °C and head and tail temperature differential <20 °C both measured in the transfer bar;
- Average fuel consumption <1.3 MJ/kg;
- Reliability > 99.0%;
- Easy maintenance, approaching 24 months campaign in between scheduled shut downs;
- Optimized ratio control and burner operation;
- NOx emission below the most severe norms, without use of expensive catalytic NOx absorption.

1.2 Ration Control

An unstable and inconsistent ratio is the source of important furnace malfunctioning, among which the most important are:

- Less energy efficient furnace operation
- Higher (with more combustion air) or harder (with less combustion air) scale formation

Higher NOx emission (with more combustion air) or CO in the waste gas (with less combustion air).

Table 1. Influence of air excess on furnace efficiency (5% design value with natural gas firing)

Item	Air excess 5%	Air excess 10%	Air excess 15%	Air excess 20%	Air excess 25%
Average fuel consumption (MJ/t)	1,300	1,318	1,344	1,377	1,420
Average scale formation (%)	0.7	0.9	1.15	1.35	1.5

Table 2. Potential extra costs for an excessive air/gas ratio

Additional cost due to wrong ratio	Air excess 5%	Air excess 10%	Air excess 15%	Air excess 20%	Air excess 25%
For extra fuel (USD)	-	416,000	1,126,000	1,971,000	3,072,000
For extra scale formation (USD)	-	9,470,000	21,307,000	30,777,000	32,880,000
Total extras (USD)	-	9,886,000	22,433,000	32,748,000	40,952,000
Total extras on revenue (%)	-	0.21	0.47	0.69	0.86

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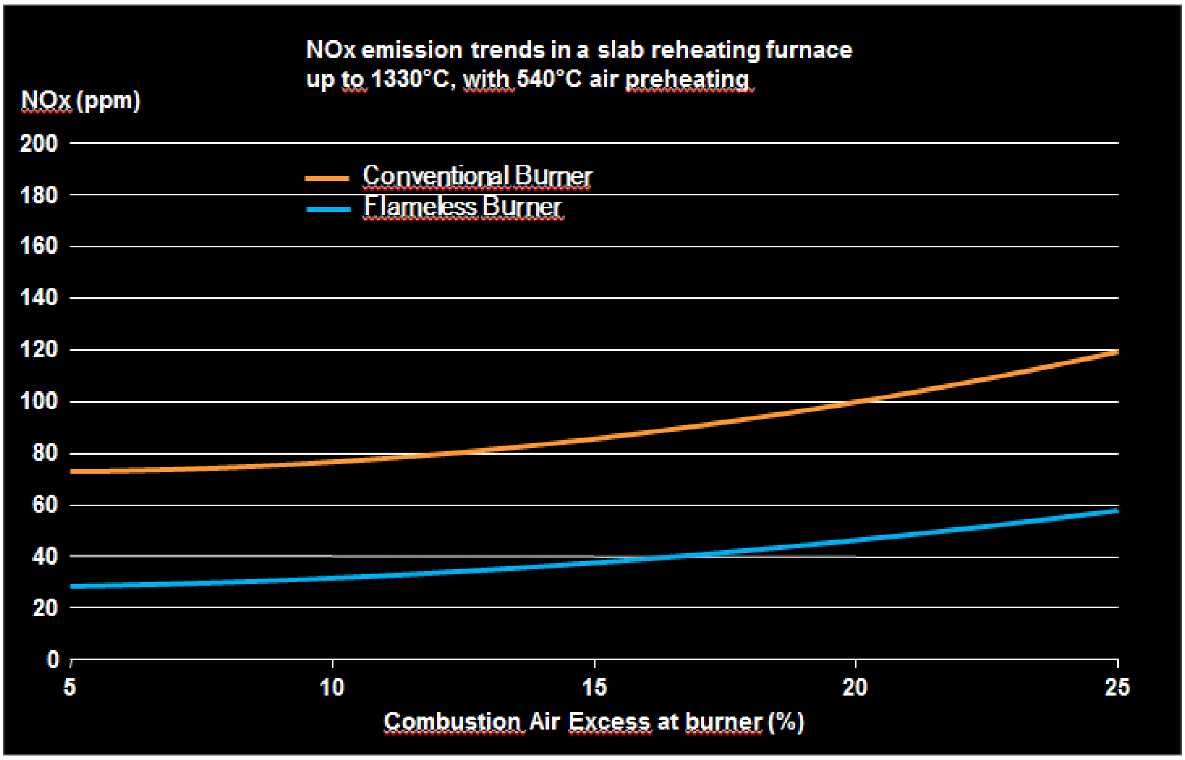

Figure 1. Nox emissions of DCC's MAB standard burner and MAB-FL flameless burner.

2 MODERN COMBUSTION SYSTEM CONTROL

2.1 Conventional Firing

Conventional cold air firing is the simplest possible design, minimum capital investment cost, maximum operational cost.
Conventional preheated air firing is actually the most used design, requires additional capital investment for centralized recuperator, reduces sensibly consumption and operational cost
Oxygen enriched air firing increases furnace's efficiency by reducing waste gas amount and by improving heat radiation exchange factor; due to its cost, it is mainly used where Oxygen is available on the plant from other processes.

2.2 Regenerative Firing

Regenerative firing Air only allows for higher air preheating without the need of costly materials for recuperator or pipes; compatibly with process requirements, the unfired zone may shorten because the majority of the heat recovery is done in the regenerators and not in the furnace.
Regenerative firing Air & Fuel allows combined preheating of air and gas (fuel) and could be interesting whenever the low heating value of the fuel is below 1,000 kcal/Nm3; however, great care shall be taken to solve the problem of unburnt fuel discharging to the atmosphere at every burner shut off cycle, which, due to regenerators' volume, could easily reach 3% of the total flow.

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2.3 Flameless Firing

Whenever above ~ 900°C, flameless burners provide significantly better heating homogeneity and lower NOx emission; they can be used for preheated air, oxygen enriched and regenerative firing.

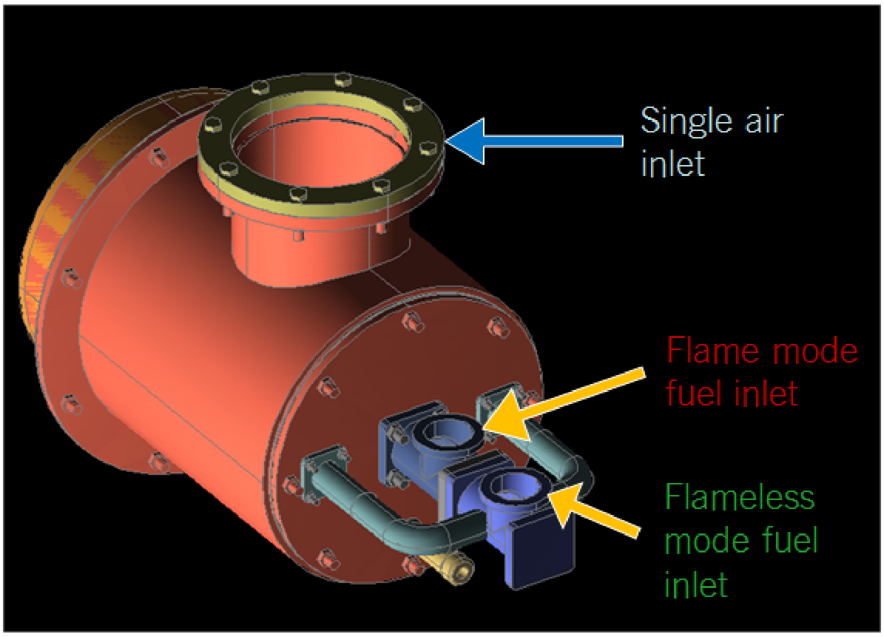

Figure 2. Flameless firing.

2.4 On-Off firing

ON_OFF firing increases overall efficiency by operating burners always at design conditions; when a burner works below 70% of its design capacity, the flame loses stability and length. The effect is that on all combustion zones equipped with side burners the flame does not reach the center of the furnace and might overheat the slab head or tail. In all zones equipped with longitudinal burners the flame loses its kinetic energy and thus “shortens” the zone effective reheating capacity.

3 TOOLS FOR WORKING OUT THE CORRECT CONTROL DESIGN STRATEGY

Provided that the specific project requirements have been properly investigated and the burner’s technology chosen, the design of the combustion system must be completed by selecting the applicable control philosophy.
Independently from the firing mode choice, Process Engineers have available several “tools” for working out the correct control design strategy:

3.1 Temperature Control Loop

This closed loop controls the furnace temperature by comparing actual measured T with set T and thus sending the required heat input variation to the flow controller.

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3.2 Flow Control Loop

This closed loop controls both fuel and air flow rates by comparing the actual measured flow with the internally set flow, calculated as a function of the heat input variation. Compensations on temperature, pressure and density are used where necessary:

Temperature compensation

$$Q_R = Q_M \sqrt{\frac{T_D}{T_M}}$$

Temperature & Pressure compensation

$$Q_R = Q_M \sqrt{\frac{T_D}{T_M}} \sqrt{\frac{P_M}{P_D}}$$

Temperature, Pressure & Density compensation

$$Q_R = Q_M \sqrt{\frac{T_D}{T_M}} \sqrt{\frac{P_M}{P_D}} \sqrt{\frac{\delta_D}{\delta_M}}$$

Where:

Q_R = **Orifice plate design flow (Nm³/h)**
Q_M = **Measured flow at main collector (Nm³/h)**
T_D = **Orifice plate design temperature (K)**
T_M = **Measured temperature at main collector (K)**
P_D = **Orifice plate design pressure (mbar)**
P_M = **Measured pressure at main collector (mbar)**
δ_D = **Reference specific gravity (kg/Nm³)**
δ_M = **Measured specific gravity (kg/Nm³)**

Figure 3. Closed loop control.

3.3 Pressure Control Loop

This closed loop is used to control combustion by keeping the pressure at the collector (air or gas independently) at the set design figures. Under the assumption that all pressure drops of the system remain constant in time, flowrates are set manually once only at start-up.

3.4 Ratio Control Loop

The air/gas flow ratio control is done considering air/fuel stoichiometric value, automatic tuning at low flow rates and air excess setpoint.
Ratio deviations are reduced by using Double Cross Algorithm (DCL), which provides dynamic high/low limits to the variation of fuel flow as a function of the actual air flow and of air flow as a function of actual fuel flow. Tuning parameters are set during commissioning.

3.5 On-Off Control

1- Each burner is controlled independently thru a traditional ratio control. There will be one ratio control per burner and each burner can be operated as a single zone. Each burner has its automatic fuel and air control and shut off valves.

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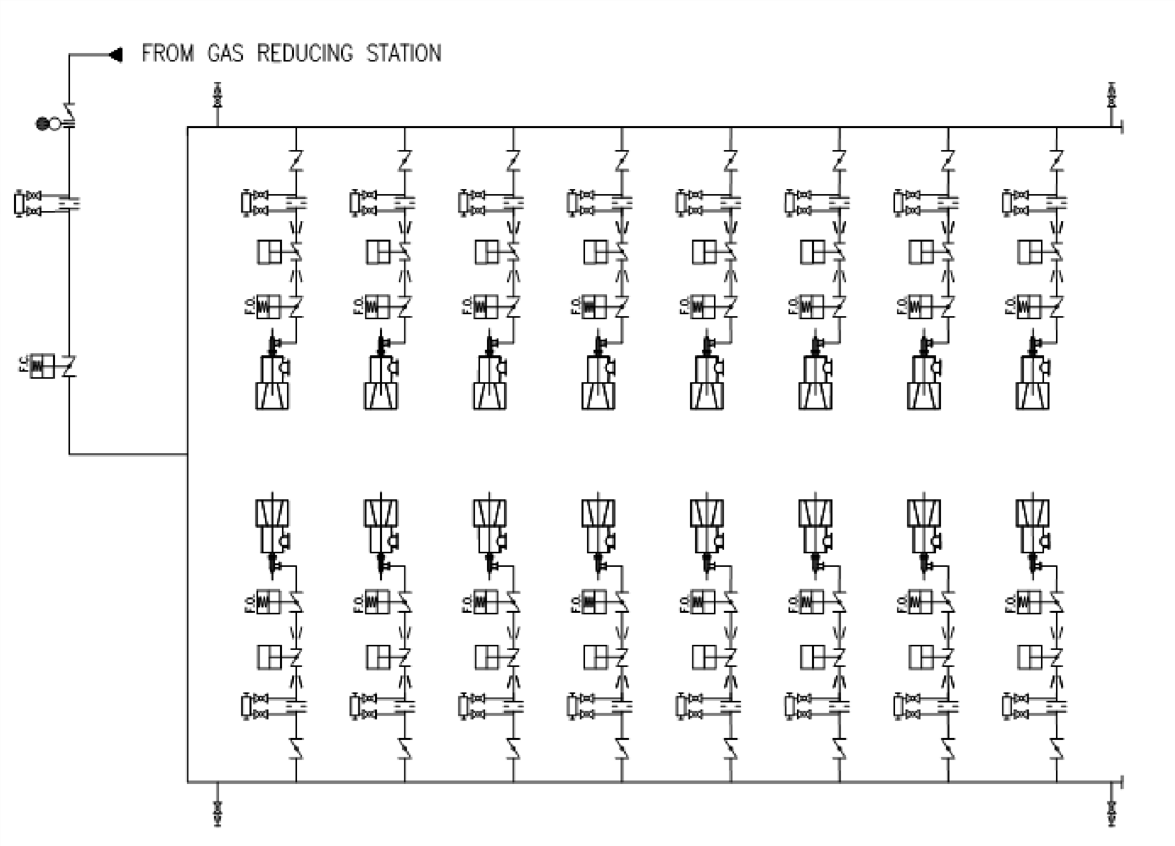

Figure 4. Traditional ratio control - one ratio per burner.

2- Each burner is fed with constant air and fuel flow. The desired ratio is set in the design and start up stage by balancing the air and gas pipeline pressure drops.
Each burner can be operated as a single zone and is equipped with automatic fuel and air shut off valves.

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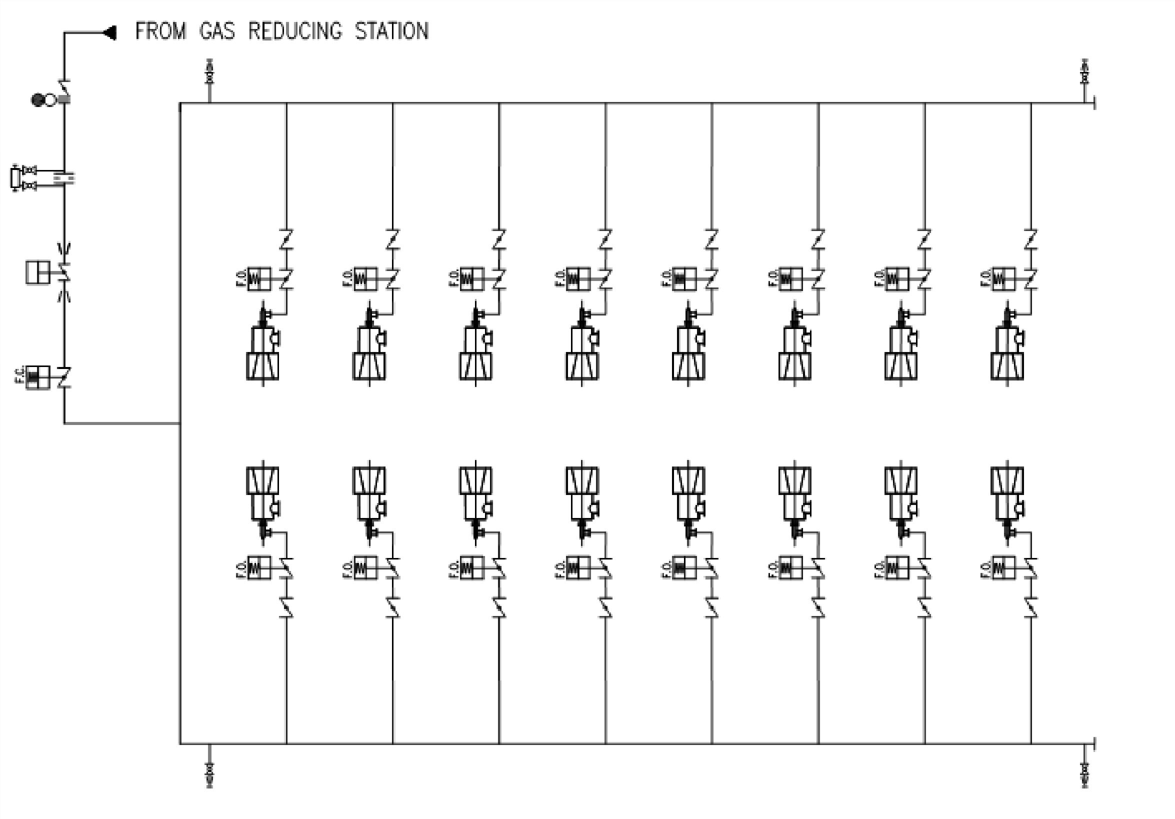

Figure 5. Fixed ratio control - constant air and fuel flow

4 PROPORTIONAL HIGH-LOW FIRING CONTROL (PHL)

ON-OFF firing offers unique process advantages and thus is today widely used; however, it was not yet supported by an efficient control system able to guarantee all advantages of this technology in a reliable and simple way.

While the conventional modulated control of each furnace zone ensures correct combustion ratio, DCC's PHL controls every burner of the zone in ON-OFF mode and thus guarantees that all burners are always working very close to the design parameters.

PHL works exactly like a conventional modulated zone with continuously controlled air / gas ratio but with on-off burners, each one equipped with automatic fuel and air shut off valves.

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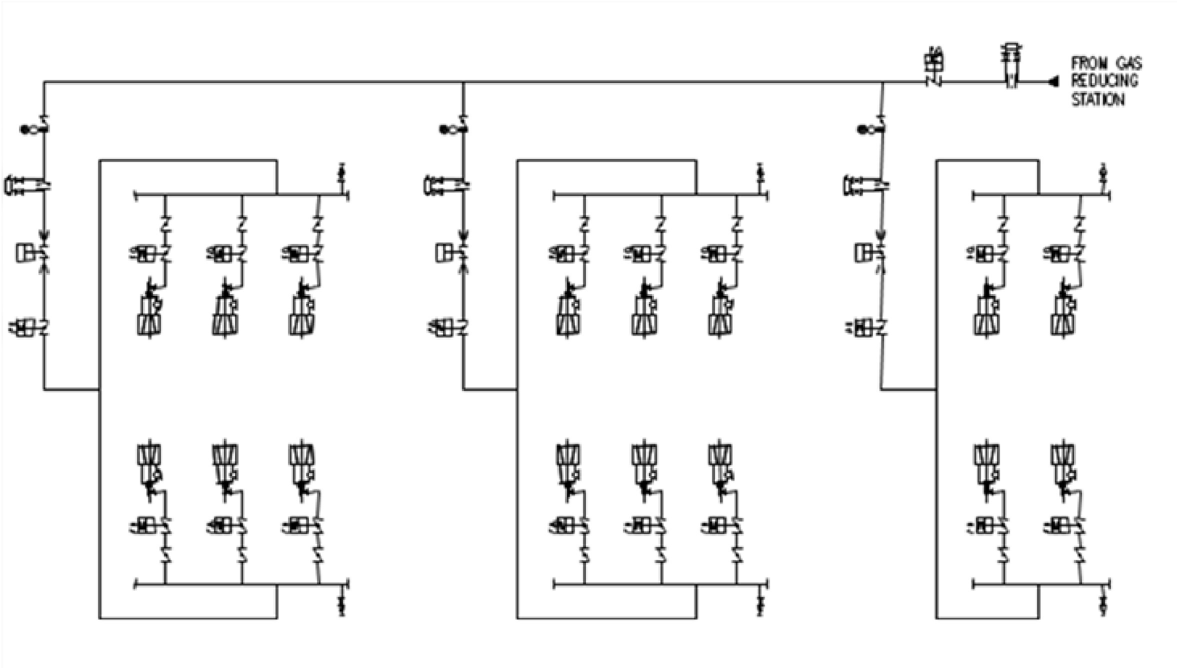

Figure 6. Proportional High-Low firing control (PHL).

PHL defines the number of burners lit, in accordance with the zone heating requirement, by dividing the actual load by the single burner nominal capacity
If the result is not an integer, the system will use a number of burners equal to the integer plus 1.
The number of cycling burners is updated continuously and the firing matrix modified automatically.
(i.e.: for a 6 burners zone with actual load of 64%, the burners lit are: 6x0.64=3.84 equal to 3+1=4 burners)
The burners are switched ON or OFF at every cycle according to a predefined matrix and after 6 cycles all burners have released the same heat amount (see next page animation), leading exactly to the required 64%.

HEATING ZONE @ 64%						
STEP	Burner 1	Burner 2	Burner 3	Burner 4	Burner 5	Burner 6
1		Low			Low	
2			Low			Low
3	Low			Low		
4		Low			Low	
5			Low			Low
6	Low			Low		

Figure 7. Proportional High-Low firing control (PHL).

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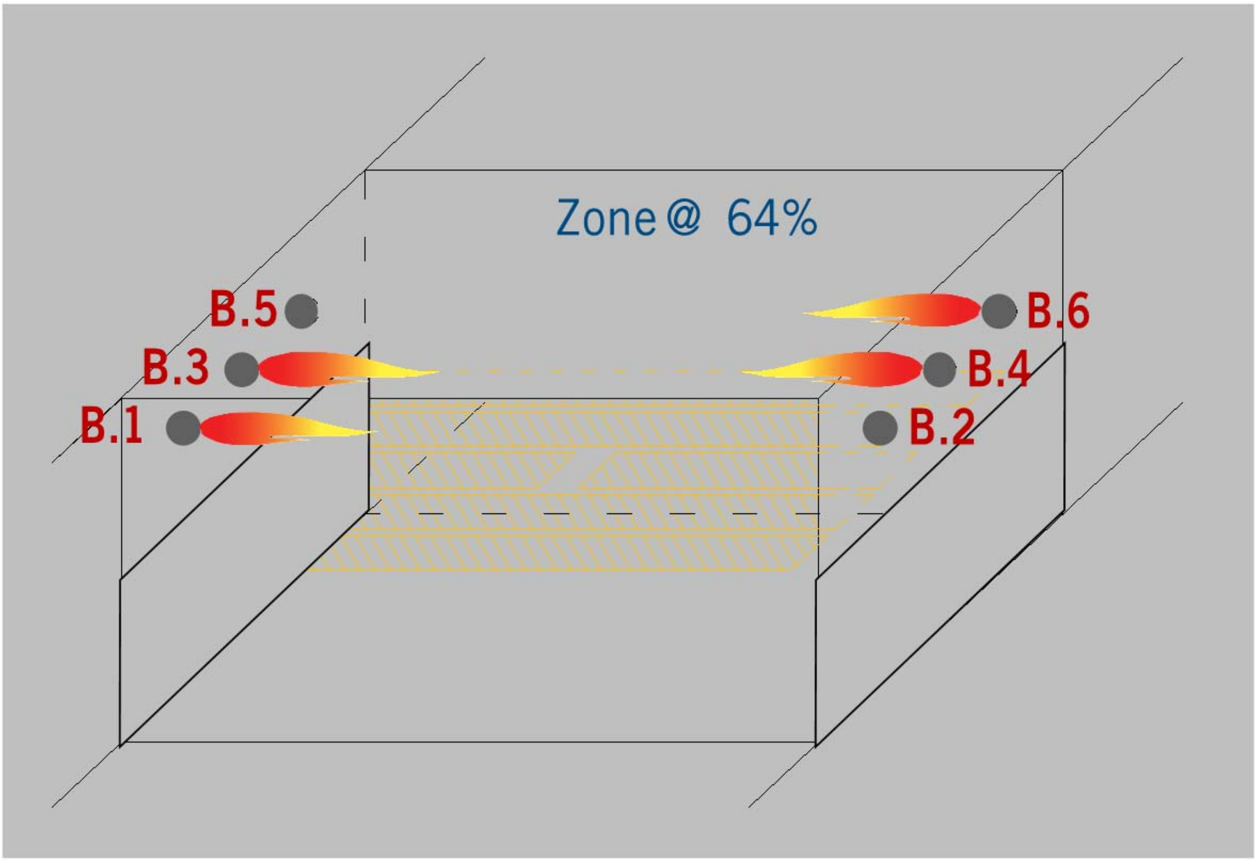

Figure 8. Proportional High-Low firing control (PHL).

5 PROS & CONS OF AVAILABLE ON-OFF SYSTEMS

Table 3. Pros & Cons of available On-Off systems 1/4

ITEM	Single burner operation with ratio control loop	Single burner operation without ratio control loop	Single conventional zone operation and PHL logic
Number of temperature control zones	One per burner		One per zone. However, if requested, each zone can be split into additional sub-zones
Ratio Control characteristics	Each burner is equipped with its own ratio control loop	There is no ratio control loop. The ratio is set in the design and tuned in the start-up stage	Each zone is conventional and therefore equipped with its own ratio control loop

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Table 4. Pros & Cons of available On-Off systems 2/4

ITEM	Single burner operation with ratio control loop	Single burner operation without ratio control loop	Single conventional zone operation and PHL logic
Number of ration control loop and burners	One per burner. For a large furnace can be up to 50-60 ratio control loops. The number of burners is minimized in order to reduce the number of ratio control loops.	No ratio control zones. For large furnaces can be up to 50-60 burners. The number of burners is minimized in order to reduce the number of zones in need to be tuned and adjusted.	One per zone. For large furnaces can be up to 10-12 ratio control loops and 60-80 burners. The number of burners is optimized according the requirements of the furnace thermal process.
Ratio control stability	Very stable because always in control. Dirty gas can be used with no problem.	Unstable because is not able to cope with possible variations of the fluid characteristics (p, T, etc.). The use of dirty gas is not recommended or impossible	Very stable because always in control. Dirty gas can be used with no problem.

Table 5. Pros & Cons of available On-Off systems 3/4

ITEM	Single burner operation with ratio control loop	Single burner operation without ratio control loop	Single conventional zone operation and PHL logic
Burner cycling time	15-60 seconds		
Zone transients	One every on and every off cycle		Marginal or none
Zone transients deficiencies	During each on or off cycles there is a transient period during which the air valve and the fuel valve closes or opens. Since the characteristics of those valves might be different it is almost certain that the ratio is altered during each transient.		When a burner of a zone closes (or opens), the whole zone is marginally affected by this transient because when one burner is closed another one belonging to the same zone is opened.

Table 6. Pros & Cons of available On-Off systems 4/4

ITEM	Single burner operation with ratio control loop	Single burner operation without ratio control loop	Single conventional zone operation and PHL logic
Furnace pressure transients	One every on and off cycle		None
Furnace pressure transients deficiencies	Potential severe pressure spikes during each transient		None
Capital investment	Requires higher initial capital investment	It is the cheapest solution	Requires higher initial capital investment

4 CONCLUSIONS

Pulse firing technology is the only one able to continuously guarantee the best burner performance during all production rates dictated by the mill operation.

The right selection of the combustion system, made by balancing all boundary constraints imposed by the plant, is a must.

The combustion technology must always be complemented by an accurate control system.

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Figure 12. Reheating Furnace with pulse firing technology

With reference to the sole ratio control we proved that a badly-designed combustion system as well as applicable controls can be the source of major draw backs both in terms of economics and environmental implications.

Due to the complexity of this matter we recommend that combustion issues for reheating furnaces are approached only by reliable furnace Engineers with comprehensive process knowledge and ability to cope with this subject from a global point of view.