Improving burner performance

Celebrating its centenary in 2020, France-based burner specialist Fives Pillard, part of Fives Company, will be launching its new Pillard NOVAFLAM® evolution burner. The new design is the product of a decade-long programme to improve the performance of the burner.

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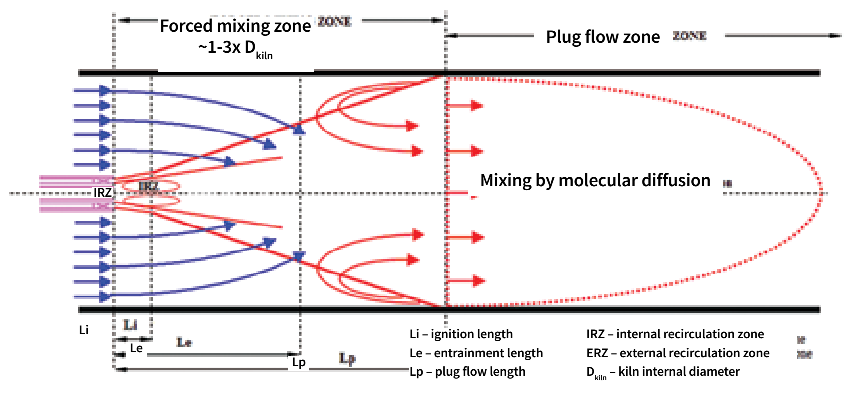
The kiln burner is rightfully considered as playing a key role in the cement plant. It must solve not only several operational and cost-driven challenges but also increasingly-important environmental issues. Therefore, the burner's design is expected to enable:

- an optimal thermal profile to maximise clinker quality and production rate
- high fuel flexibility with the best efficiency whatever the fuel, and a wide range of flame shaping adjustment options
- increased plant availability by using robust technology that can withstand extreme kiln conditions over time and feed back reliable data to the kiln operator for process control and preventive maintenance.

Figure 1: flame aerodynamics



The optimal thermal profile

As shown by the Ono method for clinker quality control, the kiln thermal profile (heating rate, maximum temperature, burning time and cooling rate) has a direct impact on the clinker crystallography and properties such as hydraulic activity (see Table 1). A rapid heating rate in the upper transition zone is required to control the size of alite crystals while the temperature in the burning zone must be sufficiently high to generate an efficient radiative heat exchange. The cooling rate must be as fast as possible.

The optimal profile is achieved if the burner is able to control the mix of fuel and secondary air, as well as ensure a short ignition distance (especially for challenging fuel types). The key to fuel and secondary air mixing is the burner's momentum. Using only 10 per cent of combustion air, the burner must be able to generate a sufficient entrainment force to quickly mix the 90 per cent hot secondary air with the fuel.

Burner momentum is the force generated by the primary air and fuel injections. It is responsible for the mixing of secondary air and fuel, and is expressed as follows:

Momentum (N) =
∑ mass flowrate (kg/s) x velocity (m/s).

In addition, the momentum must be proportional to the burner's heat release. This is called specific momentum (N/MW). Thanks to an appropriate momentum, secondary air is efficiently mixed in the forced mixing zone (1-3x the kiln diameter).

Table 1: burning conditions and microscopic character of alite and belite (cf Ono method)

Burning conditions	Hydraulic activity			
	4 – excellent	**3 – good**	**2 – average**	**1 – good**
Heating rate Size of alite (µm)	Quick 15-20	– 20-30	– (25) 30-40	Slow 40-60 (120)
Maximum temperature Birefrigence of alite	High 0.010-0.008	– 0.007-0.006	– 0.006-0.005	Low 0.005-0.002
Burning time Size of belite (µm)	Long (20) 25-40 (60)	– (15) 20-25	– (10) 15-20	Short 5-10
Cooling rate Colour of belite Birefrigence of belite Content of alpha belite	Quick Clear (C) 0.012 Abundant (40%)	– Faint yellow (FY) 0.015 Medium (20%)	– Yellow (Y) 0.017 Few (10%)	Slow Amber (A) 0.018 Nil (0%)

Figure 2: effect of axial and radial injection distribution on flame length

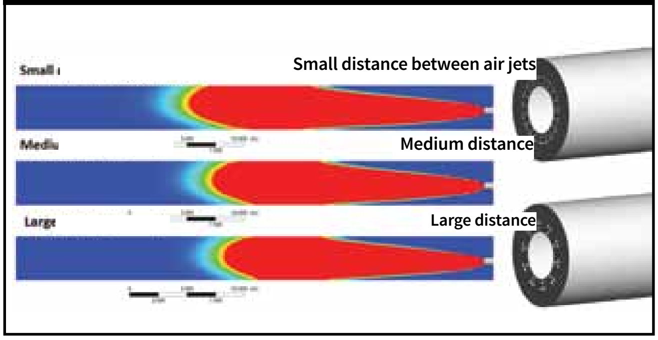
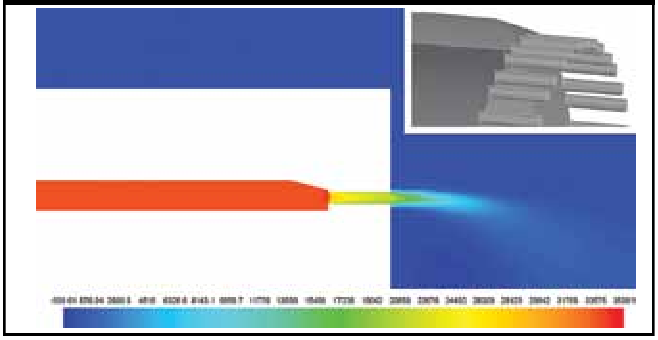


Figure 3: significant pressure drop due to sudden contraction in a "straight" axial tip hole



If momentum is insufficient, the mix will be carried out poorly in the 'plug flow zone', with a high risk of oxygen stratification, CO presence and a long flame (see Figure 1).

Fuel flexibility and wide-ranging adjustment options

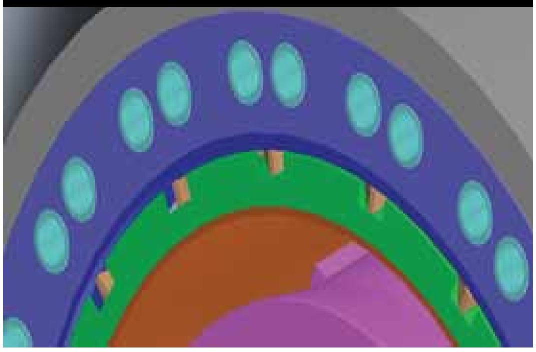
Fuel choice strategies vary over the world. Selecting the right fuel depends mainly on local availability, price and environmental concerns. As an example, high alternative solid fuel (ASF) substitution rates are often viewed as lowering operating expenditure but also help to reduce CO_2 and NO_x emissions. Achieving an ideal thermal profile with a short and intense flame when firing coal with a medium-high volatile content is relatively easy. However, firing petcoke, anthracite with low volatile content (<15 per cent) or natural gas, which require a higher ignition temperature (>600˚C), prove more challenging, and even more so when maximising the ASF substitution rate.

Moreover, fuel versatility adds complexity to the operation of the kiln. In addition to daily process or chemistry issues, each type of fuel carries further requirements due to its own chemistry, such as sulphur or chlorine content, which often lead to build-ups in the kiln and calciner. For this reason, the ability to easily change flame shape and quickly return to the original burner settings when needed is key.

A reliable and 'smart' burner

The kiln burner is subject to extreme conditions. At the tip end, the flame temperature can reach around 2000˚C in a dusty and chemically-aggressive atmosphere.

Figure 4: 3D model of the burner tip including the axial air inserts



In addition, the pulverised fuel/ASF channels suffer from wear and must be carefully designed in terms of velocity and choice of materials, particularly addressing the potential risk of plugging (sticky petcoke or alternative fuel). A poorly-engineered burner with low reliability will severely impact production and process stability.

Burner design should be of a robust construction to minimise maintenance and, just as importantly, any repair work should be easy to carry out with the shortest possible downtime.

Following Industry 4.0 trends, modern burners should be able to communicate and exchange data in real time to support predictive maintenance and remote process optimisation.

Combining major innovations to face future operational challenges

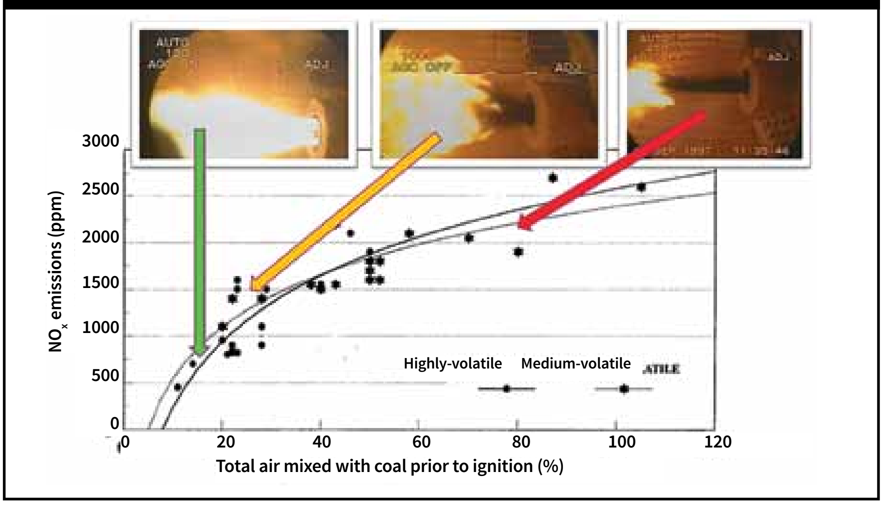
The Pillard NOVAFLAM® evolution burner combines major innovations to address future kiln operation challenges.

Higher momentum efficiency

Intense R&D work, supported by hundreds of site surveys and internal computational fluid dynamics (CFD) engineering has helped Fives Pillard to precisely determine which burner criteria have a positive or negative impact on the kiln thermal profile.

It has been shown that burner momentum is a significant criterium that is currently used by most burner manufacturers. However, it is not the only one to characterise mixing. The burner tip geometry and method of

Figure 5: NO_x emissions vs share (%) of total air mixed to coal prior to ignition – CEMFLAME consortium (IFRF – 1992)



fuels/primary air mixing plays a major role in the flame profile. Thanks to R&D engineering, a Pillard NOVAFLAM evolution burner with 9N/MW momentum can produce a better mix than a 11N/MW conventional burner, leading to capital and operational expenditure savings.

Figure 2 shows how the distribution of primary air injection (axial and radial air) impacts the air-fuel mix and therefore, the flame profile.

Optimised axial tip geometry for energy savings

A point often neglected by most burner OEMs is the burner tip's pressure drop. Depending on the way air acceleration is achieved up to the discharge point (burner tip exit), the pressure drop can be significantly high. This means that, if the burner tip is not designed to minimise pressure drop, the effective momentum will be much lower than expected, downgrading the mix and wasting energy (see Figure 3). For example, considering an air injection of 2000Nm^3/h at 100˚C and 300mbar at the burner tip inlet, if the pressure drop in the tip is 10mbar, the momentum generated by the air jet would be around 180N. However, if the tip pressure drop is 80mbar, this momentum would be around 160N, down 11 per cent.

For this reason, Fives has developed a patented technology for the Pillard NOVAFLAM evolution, consisting of 3D printed axial air inserts (see Figure 4) with optimised shapes. This minimises the pressure drop to <10mbar as well as reducing stickiness and build-ups of burner tip dust.

In addition, such inserts can be replaced by new ones with a different cross-section or design should the burner require adaption to a different configuration. This avoids a full axial tip change, saving investment costs.

Pillard RST™ swirler for highest fuel flexibility

As proven by CEMFLAME research work in 1992 (see Figure 5), flame ignition distance from the burner tip plays a key role in thermal profile control. Furthermore, with a correct ignition distance, a better combustion kinetic is achieved, resulting in lower NO_x emission levels irrespective of the fuel type used.

If the ignition distance is too long, the effect of the primary air on flame shaping is significantly reduced, generating an uncontrolled ignition point, higher NO_x emissions and increasing the risk of damaging the kiln refractory lining.

If the ignition distance is too short, the burner tip temperature increases and can generate the adhesion of dust with build-up on the burner tip. The flame can easily deviate, reducing the lifetime of the burner and kiln refractory lining.

To achieve the optimised fuel ignition distance, the Pillard NOVAFLAM evolution burner is fitted with the Pillard RST swirler. To control the ignition distance and maintain an adequate fuel injection velocity, the Pillard RST (see Figure 6) generates an internal 'reverse flow' zone in the flame's core, recirculating hot combustion gases with a low O_2 concentration back to the burner tip, creating a O_2-lean zone in the flame core, favouring fuel ignition, flame stability and NO_x reduction.

While traditional burners have a fixed swirl angle (limiting flame shaping ability and compromising on the momentum), the Pillard RST technology of the Pillard NOVAFLAM evolution was developed both for swirl air and natural gas to obtain maximum swirl efficiency. This enables a wide range of swirl angle adjustments while the burner is in operation, ie from a completely-

Figure 6: Pillard RST™ swirler effect at various injection angles

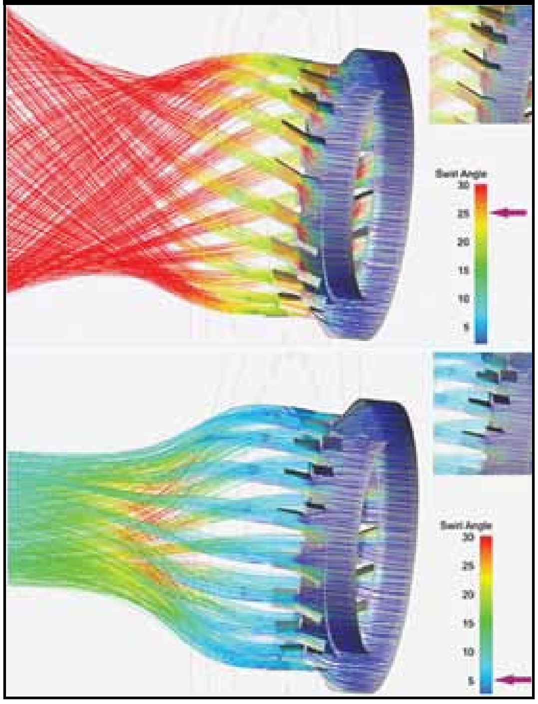
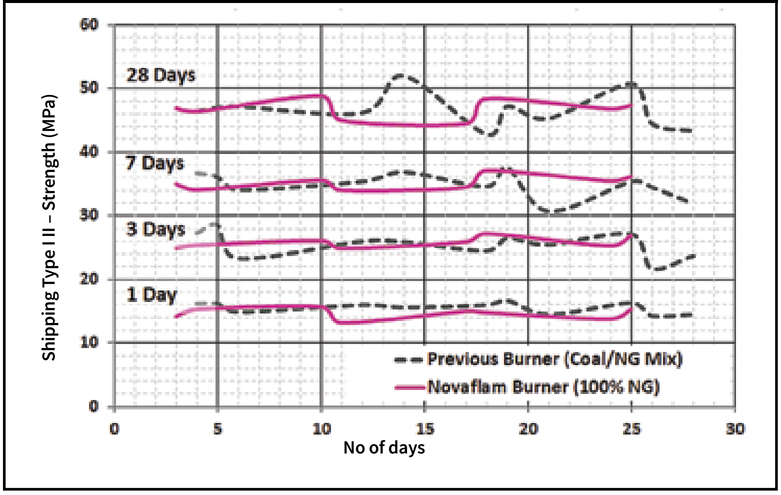


Figure 7: strength comparison between Pillard NOVAFLAM® firing natural gas and the previous burner firing a natural gas/coal mix



axial flame to a highly-rotational flame (0-40˚ swirl injection angle). Pillard's RST swirler technology allows a totally-independent swirl and momentum adjustment to be achieved with a wide range of settings, from a swirl N° of 0 to 0.4 and from a specific momentum of 4-12N/MW.

As a result, the Pillard RST allows greater fuel flexibility. For example, when switching from coal to high-sulphur petcoke, it is possible to minimise the swirl air angle without reducing burner momentum, leading to a thinner flame. Sulphur volatilisation is reduced, without compromising on combustion efficiency.

Adjustable natural gas tip cross-section

When firing 100 per cent natural gas, the primary air momentum has a limited impact on the secondary air entrainment force. Indeed, the majority of the momentum is generated by the gas itself, due to the high injection pressures (often higher than 400mbar). For example, 5000Nm³/h of natural gas (85MW) injected at 20˚C and 450mbar already generates a momentum of around 610N or 7.2N/MW. As a result, it is of utmost importance to control the natural gas momentum independently from the gas flowrate while the burner is in operation.

The Pillard NOVAFLAM evolution is fitted with an adjustable gas tip cross-section that allows a constant exit gas velocity to be maintained when the flow rate is reduced, thereby keeping a stable thermal profile whatever the kiln operating conditions are (see Figure 7). This ensures a good air-gas mix and an optimised combustion, allowing the kiln to operate under low excess air conditions (1-2 per cent O_2 at the kiln feed end) without CO and minimising NO_x emissions.

Without this option, lowering the natural gas load at the burner by 20 per cent will automatically reduce the gas pressure by 36 per cent and the specific momentum by 20 per cent (from 7.2 to 5.8N/MW).

Pillard PGZ nozzle

To reduce NO_x emissions during gas firing, the Pillard NOVAFLAM evolution can be fitted with a patented flame front stabiliser – the Pillard PGZ nozzle (see Figure 8). The PGZ nozzle uses Pillard's BLUEMix® technology, a 'permanent flame' where a small amount of natural gas is injected in the burner centre, allowing stabilisation of the main gas flame, reducing the ignition distance and generating HCN and NH_3 radicals, favouring NO_x reduction. Recent feedback from a site in Europe confirms a NO_x reduction of around 30 per cent.

Pillard Airless Stabiliser

The location of the fuel injection with respect to the primary air injection (axial and radial air) is key for optimised flame control and NO_x emissions. Locating the fuel injection inside the radial air channel is the optimal position. The NO_x is reduced in the flame core by the combustion of part of the fuel in an O_2-lean zone, creating NO_x reburning conditions by recirculating the flue gas and hydrocarbon radicals (see Figure 9).

To this aim and to further minimise O_2 content in the flame core as well as

Figure 8: flame front stabiliser

Figure 9: NO_x reburning zone

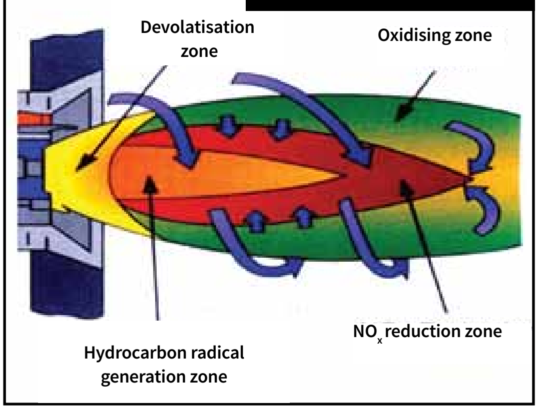



Figure 10: airless stabiliser

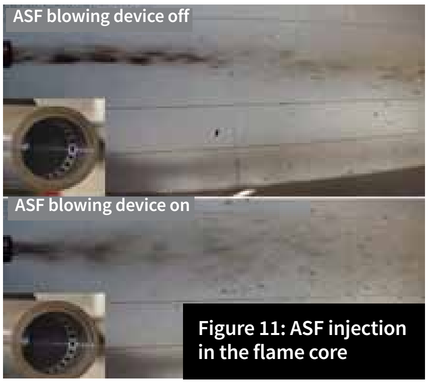


Figure 11: ASF injection in the flame core


Figure 12: fast removal of burner tip

to improve NO_x reduction, the Pillard NOVAFLAM evolution burner can be fitted with a special ceramic shell, a 3D-printed Pillard Airless Stabiliser (see Figure 10). This device improves flame stabilisation and avoids injecting cooling air in the central part of the burner.

Pillard Injectors for ASFs

ASF characteristics can vary widely in terms of size, moisture and composition, requiring adapted burner settings to achieve the maximum substitution rate. For this purpose, the Pillard NOVAFLAM evolution burner enables a central injection of ASF by means of dedicated injectors (see Figure 11) specifically engineered to cope with various ASF densities and size parameters. This not only achieves a longer residence time for large or dense particles but also avoids the 'double flame' effect for flying particles.

Burner reliability and 'SMART' data

The Pillard NOVAFLAM evolution burner package has been developed in line with the following principles:

- A robust and simple design for flame control:
  - – no moving parts exposed to fire
  - – no 'bowl effect' to prevent dust recirculation and its consequential wear of the steel surfaces exposed to flame radiation.
- A new mechanical design of the axial tip, allowing free expansion under wide temperature variations, thereby reducing potential 'fissuring' issues.

In addition to the above, some options can be proposed for specific cases:

- A 'ceramic kit', for specific parts exposed to abrasion (such as the centring plate and coal inlet), using 3D printing technology.
- If dust sticking to the tip is a persistent issue, the burner can be fitted with a special, patented air-cooled scraper, which cleans the tip during operation.

Furthermore, the burner tip has been designed for easy assembly and dismantling to reduce kiln downtime (see Figure 12).

With these mechanical devices, the Pillard NOVAFLAM evolution burner design provides a sturdy construction and easy dismantling, reducing downtime as well as providing improved operational expenditure.

To prepare the future of the cement industry, Pillard NOVAFLAM evolution burners can also include digital features, through a NOVASMART™ device (see Figure 13), specially developed to facilitate burner maintenance and optimisation, including capabilities such as:

- detection of a burner position fault
- detection of burner refractory issues
- detection of a burner tip fault
- continuous calculation of swirl number, momentum, fuel injection velocity, with the possibility of controlling the momentum for an improved thermal profile and NO_x control
- possibility of correlating burner settings to the process operating conditions to facilitate burner optimisation.

Thanks to the Pillard NOVAFLAM evolution burner, it is now possible for cement plants to avoid burner failure or malfunction as much as possible, and increase their production and kiln availability in an innovative way.

Conclusion

In a complex and fast-changing world, the cement industry is facing an unstable demand for cement. With around 30 burners sold and 20 in operation, the Pillard NOVAFLAM evolution technology brings resilience to clients. Thanks to high flexibility and modularity, the Pillard NOVAFLAM evolution reduces operational costs and the environmental footprint as well as enabling cement plants to achieve a high clinker quality, regardless of operating conditions. ■

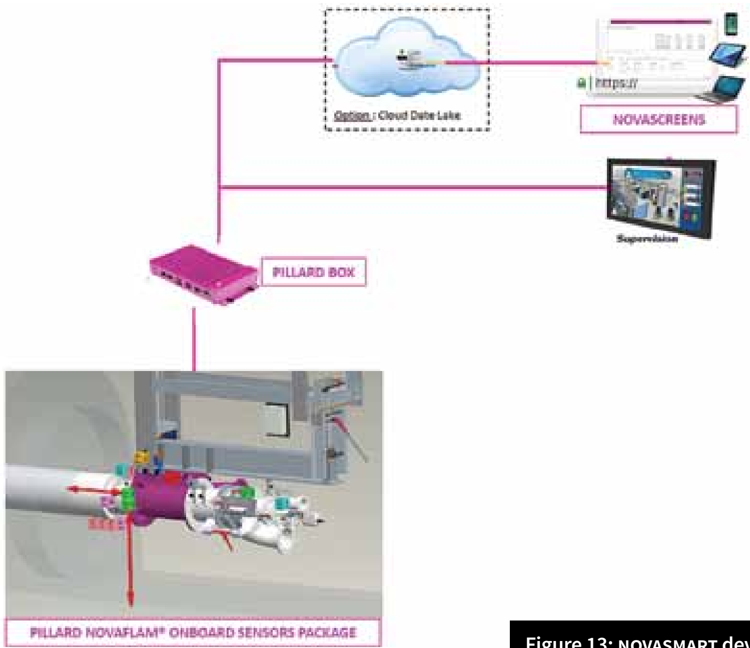


Figure 13: NOVASMART device