Gaseous fuel firing in lime kilns

FCT Combustion applies jet excitation, a fluid dynamic singularity, in its Gyro-Therm® burner to promote increased mixing rates between gaseous fuels and oxidant in lime kilns. This technology is able to simultaneously reduce specific energy consumption, kiln inlet temperature and NO_x emissions, while increasing production rates.

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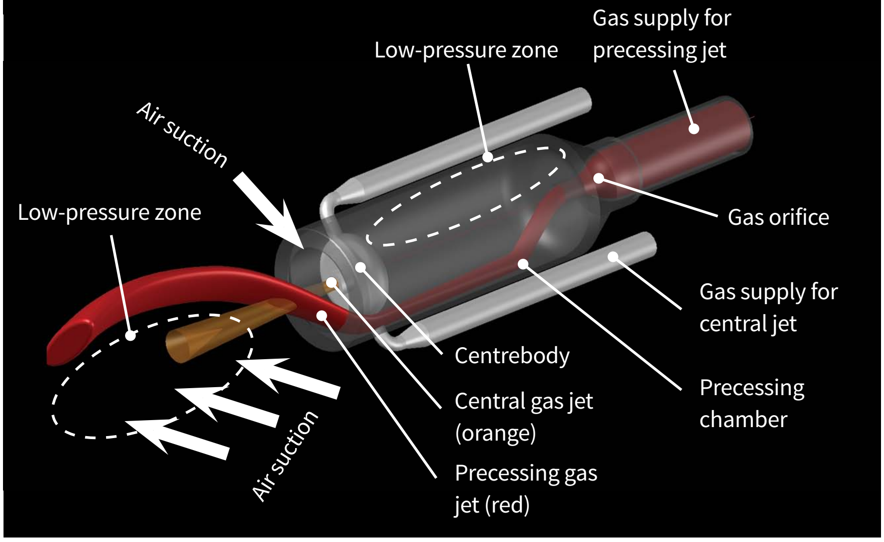
Even if it is an oversimplified statement, it is commonly said that there are three "Ts" necessary for good combustion: temperature, time and turbulence. Especially in existing equipment there are often size limitations such that it is not possible to increase the residence time. There are also often materials operational temperature or emissions limits. Therefore, the focus of combustion efficiency advances has been on improving and controlling turbulence. In simple terms, improving and controlling the mixing rate between fuel and oxidant.

Figure 1: Gyro-Therm chamber diagram



From jet stream to jet excitation

Over the years different ways to increase the turbulence have been tried and the most-frequently employed concept in modern kiln burners uses the energy contained in the fuel and/or oxidant stream to promote the mixing. This concept is based on steady-state, constant jet streams interfering with each other and with the surrounding secondary air, creating the necessary turbulence. This principle is applied in the design of most current kiln burners, including FCT's multifuel, high-momentum Turbu-Jet burner.

However, other methods do not use constant jet streams but pulsating or variable jets known as jet excitation, which take advantage of fluid dynamic singularities to promote mixing.

Jet excitation as a method of increasing mixing rates has been investigated for more than four decades. Different methods, including acoustic, fluidic and mechanical, of promoting jet excitation have been tried. However, it was not until the 1990s that an axisymmetric, well defined and replicable solution was found via the studies of GJ Nathan, SJ Hill and RE Luxton in the Department of Mechanical Engineering at The University of Adelaide, Australia.[1]

Their work concluded that a fluid passing at high speed through a nozzle into a larger chamber, with certain geometric characteristics, would precess around the chamber's longitudinal axis. This technology is the key concept of the patented FCT Gyro-Therm, used when gaseous fuel is the main fuel of the burner, either alone, with coal or fuel oil.

Gyro-Therm burners have been applied to numerous industries since 1995. A case study is presented for a lime kiln, in which it was possible to compare different operational parameters with three different burners: a fuel oil burner originally fitted to the kiln, a conventional turbulent jet gas burner installed during a conversion to natural gas, and the Gyro-Therm as an improvement for natural gas operation.

The unique properties of the Gyro-Therm burner have resulted in a simultaneous 12 per cent increase in kiln production for the same lime quality, specific fuel consumption fell by 10 per cent and NO_x emissions by 44 per cent when compared to the conventional turbulent jet burner firing gas.

Technology explained

The central feature of this technology is the Gyro-Therm chamber, which uses the static pressure of the gas to create a gas jet that exits the burner at a large angle to the longitudinal axis. The jet also changes direction at a high frequency.

The gas is divided into two streams: the precessing jet and the centrebody jet (Figure 1). The precessing jet is the majority of gas flow and is injected at high speed into the back of the chamber through a small orifice. Due to the sudden expansion in chamber diameter and fluid behaviour similar to the Coanda effect (tendency of a fluid to stay attached to a convex surface), the gas stream tends to attach to one side of the wall, creating a low-pressure zone on the opposite side of the chamber. This effect is desirable because it induces air from burner surroundings into the low-pressure zone inside the chamber, creating an initial premixing between gas and air.

At the chamber exit there is a constriction in the diameter that forces the natural gas jet to the opposite side of the burner while exiting the chamber. This creates another low-pressure zone in the centre of the flame just in front of the burner. This second low-pressure zone helps to capture additional air in the centre of the gas cloud and also slightly deflects the gas jet back to the centre (together with the deflection caused by secondary air), avoiding an excessive flame diameter.

The precessing jet is not fixed in one single position because of the inherent instabilities of the flow which force the jet to occupy successive positions inside the chamber. This creates a gyroscopic-like rotation movement, a precession around the burner longitudinal axis (see Figure 2). This behaviour is very similar to what would happen in the case of a water hose being rotated, held a metre from its extremity.

In this movement, the position of the gas jet goes around the complete circumference 30-50 times/s. In context, this would mean 10-15 complete turns per eye blink, creating a perfectly-even dispersion of the gas. No precession can be seen in the flame itself, which seems to be stationary. An animation about the operation principle of Gyro-Therm as well as a video of its flame can be found at www.fctinternational.com.

The second stream of gas is injected through a central orifice in the front of the Gyro-Therm chamber. Adjusting valves at the back of the burner changes the proportion of gas between the two channels and allows for excellent flame control. When a more central jet is chosen, the flame will become longer and slimmer. As the precessing jet fraction is increased, the flame becomes shorter and wider.

The precessing movement is continuously engulfing and renewing two main air pockets: one inside the Gyro-Therm chamber and one just in front of the burner (see Figure 3).

The air available in the pockets is not sufficient for complete gas combustion. This forces the gas to crack into carbon particles before complete burn-out. The carbon particles generated in the process increase the flame's emissivity, raising heat transfer by radiation from the flame to the product. The gas flame generated by the Gyro-Therm is, in terms of heat flux profile, more similar to a fuel oil or coal flame than to the commonly long and low radiant gas flames (see Figure 4).

The more radiative flame from the Gyro-Therm brings a series of advantages when compared to a normal gas flame. The improved heat transfer from the flame to the product results in lower kiln inlet temperatures, allowing for a higher production rate. Reducing the kiln inlet temperature also leads to lower thermal losses, decreasing specific energy consumption. This is improved even further by the higher production rates allowed. Due to a better heat flux profile, the product characteristics can be also improved.

The carbon particles, important for the improved heat transfer, subsequently burn out completely when reaching more

Figure 2: precessing jet movement

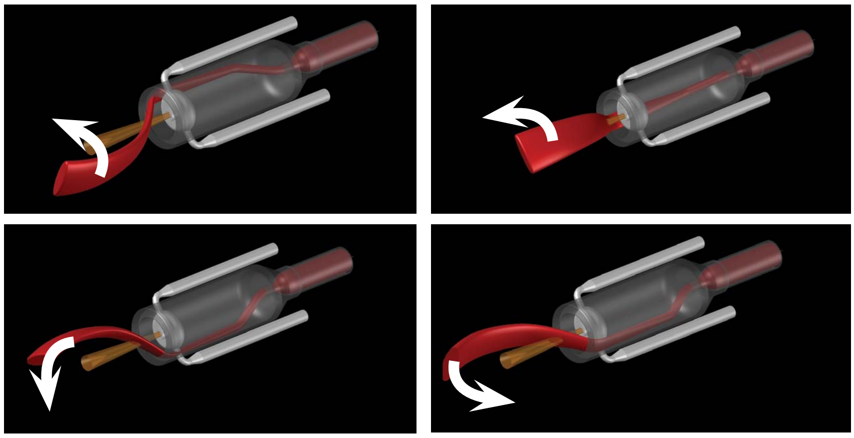


Figure 3: air pockets inside gas film

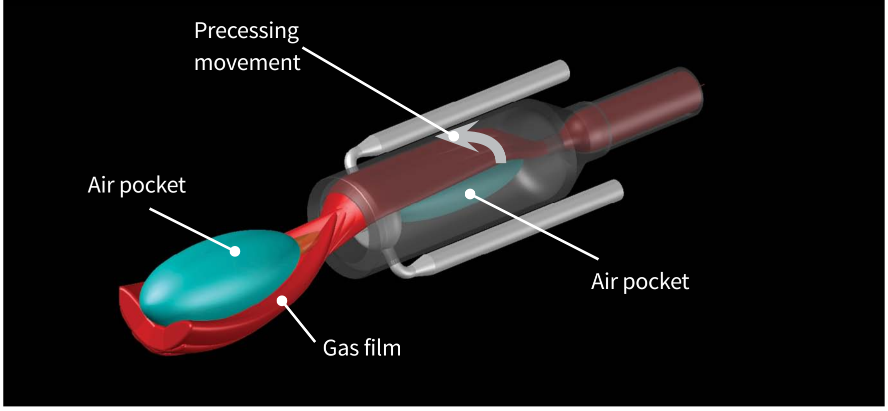


Figure 4: normal turbulent gas burner with transparent flame and poor heat transfer (left) versus Gyro-Therm flame with high radiation and improved heat transfer (right) – both pictures show burners under the same operating conditions in the same kiln and same camera setting

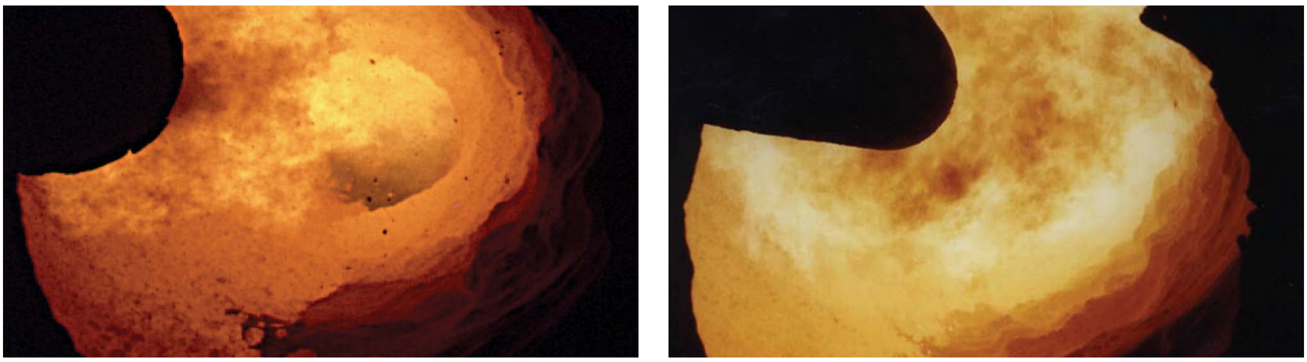


Figure 5: Gyro-Therm burner for natural gas, coal and liquid fuels firing for a lime kiln, operating on gas at kiln heating

secondary air.

As a further benefit, the improved radiation of heat out of the flame results in a decrease in the flame peak temperature. NO_x formation is therefore much reduced. Further NO_x reduction is achieved due to the presence of the carbon particles in the early stages of combustion. The NO_x reduction benefits are so strong compared to other gas burners that Gyro-Therm is quoted by US Environmental Protection Agency as best practice technology for NO_x reduction and improving combustion with gaseous fuel (see box story).

Arranged around the central precessing jet chamber are further burner channels, depending on other fuels used. A small amount of primary air is also injected when the burner has other fuel capabilities. The main function of this air is for cooling the burner while operating with gas (1-3 per cent stoichiometric air), to provide a channel for housing of ancillaries such as an ignition system and flame detection, and also to provide additional flame shape control with other fuels than gas (3-5 per cent stoichiometric air).

Energy efficiency improvement and cost-saving opportunities for cement making

A recent technology that has been demonstrated in several locations is the Gyro-Therm technology that improves gas flame quality while reducing NO_x emissions.

Originally developed at the University of Adelaide (Australia), the Gyro-Therm technology can be applied to gas burners or gas/coal dual fuel. The Gyro-Therm burner uses a patented "precessing jet" technology. The nozzle design produces a gas jet leaving the burner in a gyroscopic-like precessing motion. This stirring action produces rapid large scale mixing in which pockets of air are engulfed within the fuel envelope without using high velocity gas or air jets. The combustion takes place in pockets within the fuel envelope under fuel rich conditions. This creates a highly luminous flame, ensuring good radiative heat transfer.

A demonstration project at an Adelaide Brighton plant found average fuel savings between five and 10 per cent as well as an increase in output of 10 per cent (CADDETT, 1997). A second demonstration project at the Ash Grove plant in the US (Durkee, Oregon) found fuel savings between 2.7 per cent and 5.7 per cent with increases in output between 5-9 per cent (CADDET, 1998; Vidergar and Rapson, 1997).

Sponsored by the US Environmental Protection Agency, March 2008.

Available and emerging technologies for reducing greenhouse gas emissions from the Portland cement industry

A proprietary system called Gyro-Therm has been demonstrated at several cement plants to improve combustion and reduce fuel usage. The system is applicable to gas-fired and gas/coal-fired kilns and reportedly results in a 2.7-10 percent reduction in fuel usage and up to 10 percent increase in output of the kiln. Average costs of the system based on demonstration projects is US$0.80/annual ton cement capacity (Worrell and Galitsky, 2008), and payback time is estimated to be less than one year. (FTC, 2009)

US Environmental Protection Agency, October 2010.

Case study: Australian lime kiln

The first Gyro-Therm was supplied in 1995 and over 50 units have been delivered since to different industries. An illustrative case was a Gyro-Therm burner installed in an Australian lime kiln to replace existing burners. This is an interesting case to be presented because it allows the comparison of several kiln operational parameters during three different stages:

- Stage 1: fuel oil operation, using the original fuel oil burner supplied with the kiln
- Stage 2: after a conversion to natural gas, using a common turbulent jet burner
- Stage 3: after the installation of a Gyro-Therm burner firing natural gas.

It is very important not to underestimate the inherent changes in a process when converting to natural gas firing. For example, the amount of exhaust gases in the kiln for the same amount of energy is higher with natural gas than with fuel oil, simply because natural gas has proportionally more hydrogen in its composition. This cannot be addressed by any burner and can impact negatively, reducing production rates due to limitations on the kiln exhaust fan.

Other changes, such as flame emissivity, heat flux profile and NO_x formation, are burner specific, and there the Gyro-Therm has proven superiority.

Figure 6 provides a good reference for performance improvement that can be achieved when replacing a common turbulent jet with a Gyro-Therm, both firing natural gas. The data presented represents averages over a six-month period during the three different stages presented previously. It was possible to observe an increase in production rate of 12 per cent simultaneously with a reduction of specific energy consumption of 10 per cent and kiln back end temperature of seven per cent.

NO_x emissions in stages 2 (natural gas – common turbulent jet burner) and 3 (natural gas – Gyro-Therm) were measured continuously at kiln back end in ppm and normalised at 1.5 per cent oxygen level (as shown in Figure 7). The data points that lie at the zero NO_x ppm level are those for an air purge cycle on the instrument and indicate that the zero calibration of the instrument remained good throughout the measurements.

Average NO_x at kiln back end with a common turbulent jet burner firing natural gas was 937ppm at 1.5 per cent O_2 (or 1079mg/Nm^3 at 10 per cent O_2). The same measurement with a Gyro-Therm burner firing natural gas averaged 524ppm at 1.5 per cent O_2 (or 604mg/Nm^3 at 10 per cent O_2), representing a reduction of 44 per cent. The NO_x reduction is ever greater when considering the NO_x emissions (in ppm or mg/Nm^3) per tonne of product, as the production rate increased by 12 per cent with a Gyro-Therm installation.

Conclusions

Conversions to natural gas present issues inherent to natural gas composition, but there are also other challenges that can be addressed by burner design. Using the unique and patented technology of Gyro-Therm, FCT is able to overcome those burner-specific issues, increasing production rates, reducing specific energy consumption, kiln back end temperature and NO_x emissions, for a profitable and environmental-friendly operation. ■

Figure 6: production rate increase and specific energy consumption decrease when using Gyro-Therm

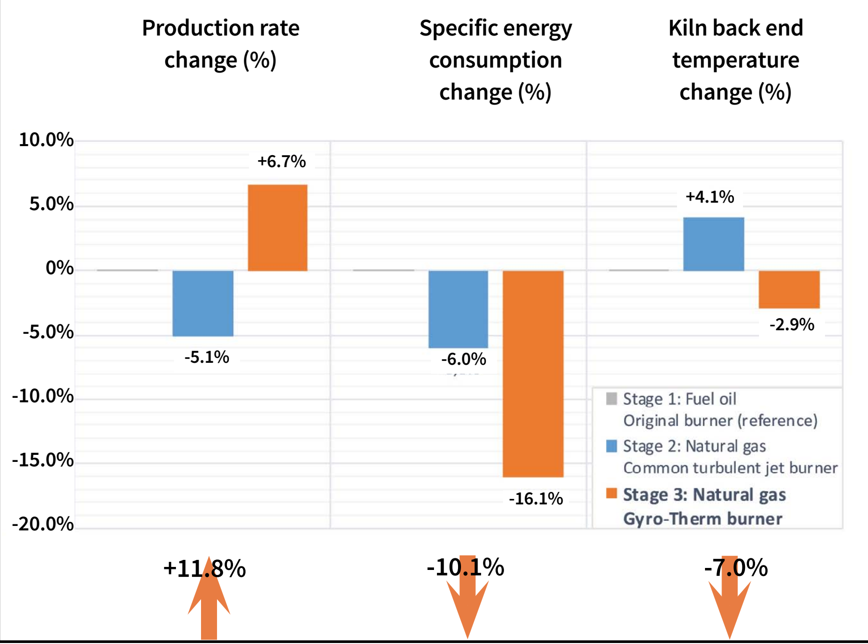
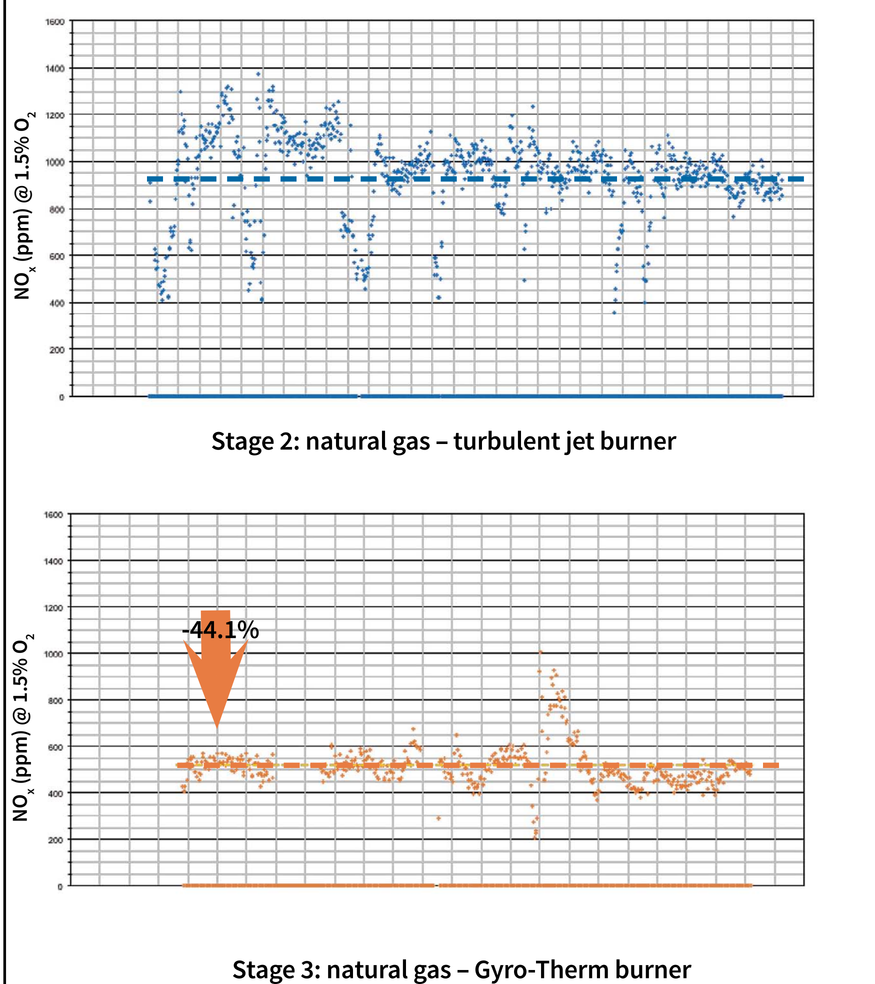


Figure 7: NO_x emissions decrease when using a Gyro-Therm burner – top: stage 2, natural gas – turbulent jet burner • bottom: stage 3, natural gas – Gyro-Therm burner



REFERENCES

[1] HILL, SJ 'Improving Lime Production with Gyro-Therm Burners' in: *Global Lime*.

[2] NATHAN,GJ, HILL,SJ.AND LUXTON,RE (1998) 'An Axisymmetric Fluidic Nozzle to Generate Jet Precession' in: *Journal of Fluid Mechanics*, 370, p347-380.

[3] UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (2010) *Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from the Portland Cement Industry* prepared by Office of Air and Radiation, Oct.

[4] WORRELL, E AND GALITSKY, C (2008) *Energy Efficiency Improvement and Cost Saving Opportunities for Cement Making, An Energy Star® Guide for Energy and Plant Managers* prepared by Ernest Orlando Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division, sponsored by the US EPA, March.