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Advanced Combustion Equipment For Continuous Furnaces

Ambrogio Milani and Joachim Georg Wünning

WS Wärmeprozesstechnik
Renningen, Germany

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Corresponding Author(s):

Ambrogio Milani
WS Wärmeprozesstechnik
Renningen, Germany

Tel. No. : +39 010 215068
Fax : +39 010 215068
E-mail : ambrogio.milani@fastwebnet.it

ABSTRACT

The following report reviews modern technology of regenerative burners with emphasis on heat recovery and flameless combustion techniques for high temperature processes.

Performance of the combustion equipment are most important in large strip-line furnaces not only for energy savings and NOx abatement, but also for reliable, trouble free operation.

The paper describes a modern, compact regenerative burner that has been extensively installed and tested on industrial furnaces and assesses related features. Significant and successful applications to large Annealing and Pickling lines for stainless steel strip are reported.

Industrial practice and field feed-back point out that a modern, efficient and more reliable combustion system may be competitive and that possible additional investment costs can be recovered in a short time, while providing better quality and easy operating conditions.

Keywords:
flameless combustion, burner-integrated heat recovery, regenerative burners, annealing and pickling lines

1. INTRODUCTION

Reducing energy consumption and air pollution is a crucial issue in the steel industry; large treatment and re-heating furnaces are subject to mandatory constraints regarding clean air and emission of greenhouse gases. Furnace technology is therefore challenged to seek significant improvements that may approach the general, long-term goal of energy savings ~20-50% and emissions abated ~90% with respect to the present situation. Flameless technology can comply with such requirements, making it possible to adopt extremely high air preheating in high temperature process furnaces [1].

Annealing and pickling lines ("A&P") for stainless steel strip are large continuous plants where the product (mainly austenitic steel) is annealed in free-flame tunnel furnaces at high temperature (~ >1100 °C); uniform oxidation is important for the surface quality. The coils are cold rolled then annealed again in a subsequent A&P line, where the surface quality requirements are even more strict. In these large plants, not only NOx emissions are an issue (NOx can come from combustion and pickling as well), but also productivity and good performance (uniformity, ease of operation and control) are very important as well, since they affect product quality and costs directly.

The present report describes successful installation and operation of compact regenerative burners in A&P lines [2-4].

2. HIGH TEMPERATURE COMBUSTION

Heat recovery and flameless combustion

Increasing the temperature of the combustion air by heat recovery from the hot flue gases is the straight forward way of increasing the thermal efficiency of high temperature furnaces. With burner integrated heat recovery, there is also a remarkable productivity advantage (or an equivalent reduction of plant size) to be gained in the classic arrangement of counter-current furnaces: air is preheated and flue gases are cooled inside each burner that extracts most of its own products of combustion locally. The passive zone at the stock entrance, which is used to cool down the flue gases and to recover energy via a central recuperator, is no longer needed. At the same time, the temperature profile along the furnace can peak higher: as a result, the maximum throughput for a fixed furnace length may be increased, typically by 25-30% .

A shorter furnace with a higher thermal efficiency can be realized by means of substantially higher air preheat; the burner integrated heat recovery offers a potential with respect to conventional, centralized heat exchanger at the furnace outlet, as is shown in Table 1.

Table 1 – Range of Efficiency vs Pre-Heat Temperature

Air Preheating System	Temperature Limits (°C)	Pre-heat Efficiency (%)	Thermal Efficiency (%)
Central (Tubular)	800	40	60
Burner integrated metal/ceramic	1000/1200	> 60	70
Regenerative ceramic	1250	> 80	> 80

Regenerative burners offer a large energy saving potential. Thermal efficiencies above 85 % have been reported in industrial practice [5]: the principle, well known, is based on two heat reclaiming beds alternatively heated by flue gases and cooled by combustion air. Advanced ceramic materials for the beds and nozzles (typically moulded silicon carbide), reliable heavy duty electro-valves and digital control are employed to implement the new technology.

With a process temperature ~ 1250 °C , very efficient air preheat means combustion air over ~ 1000 °C at the burner nozzle. Extremely hot air requires special burner design and mastering the combustion process: direct fuel injection into the air stream would produce exceedingly high localized flame temperatures, damaging the burner itself and producing intolerable NOx emissions, in the order of thousands of ppm while the admissible limits are below 250 ppm. It is well known that NOx increases exponentially with peak temperatures in the flame and therefore the effort of research and development for many years has concentrated on reducing down these temperature peaks.

The final result of extensive R&D work is a combustion system called FLOX®, registered trademark of WS Wärmeprozesstechnik GmbH-Renningen, which reduces NOx even below values typical of burners fired with cold air. FLOX® is suitable for high temperature processes above a threshold of ~800 °C, where the combustion chamber is above self-ignition temperature and where safety regulations dispense with flame detectors. Under such circumstances, a burner stabilized flame, attached to the burner nozzle, is no longer required. If the pure reactants, hot air and fuel (e.g. natural gas), are allowed to mix with hot combustion products entrained from the surrounding gases in the combustion chamber, then combustion reactions are brought about in a diluted environment with chemically inert partners and no stable flame can be maintained [6]. Provided that sufficient mechanical energy is imparted to the air jet in order to fully mix with re-circulated combustion products (typical of high velocity burners) and a suitable nozzle design is developed, a stable and thorough firing pattern can be found for flameless combustion. Flameless reactions take place gradually in a volume (not in a highly turbulent, two-dimensional flame front) without the typical combustion roar and without any visible flame. The visual difference between conventional and flameless combustion is shown in Figure 1.

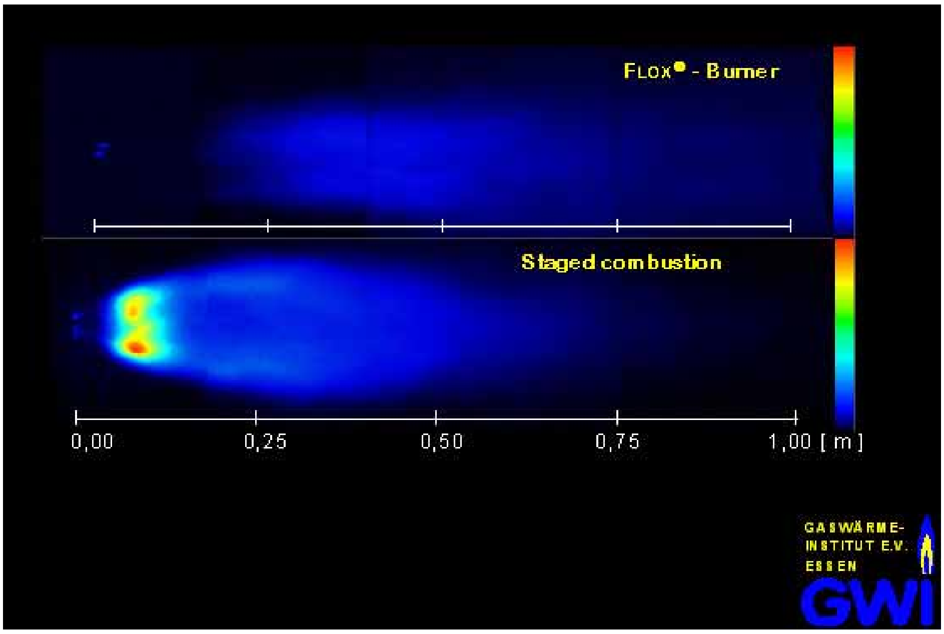

Figure 1 – Flame and flameless firing mode (after GWI [5])

The different chemistry in the FLOX® burner results in different pollutant emissions. The most impressive difference concerns NOx emissions, which can be expected because of the reduction of the gas temperature peaks (which influence NO formation) and to absence of a flame front rich in active radicals. The abatement in NOx emissions can be clearly seen in Figure 2 from accumulated data and assuming efficient air preheat (order of 60-75% of flue gas temperature). NOx is abated by one order of magnitude with respect to the best staging design. It should be remembered that the development of the flameless technique was first driven by low NOx investigations and that practical application of high air temperature (for energy saving purposes) has been hindered for a long time because of high NOx emissions.

3. HIGH VELOCITY, REGENERATIVE BURNERS

In order to implement flameless firing in practical burners, plant start-up from cold conditions must be taken into account as burners cannot be fired in the flameless mode until the safety threshold (~ 800°C) is surpassed. This may be carried out by providing two separate gas

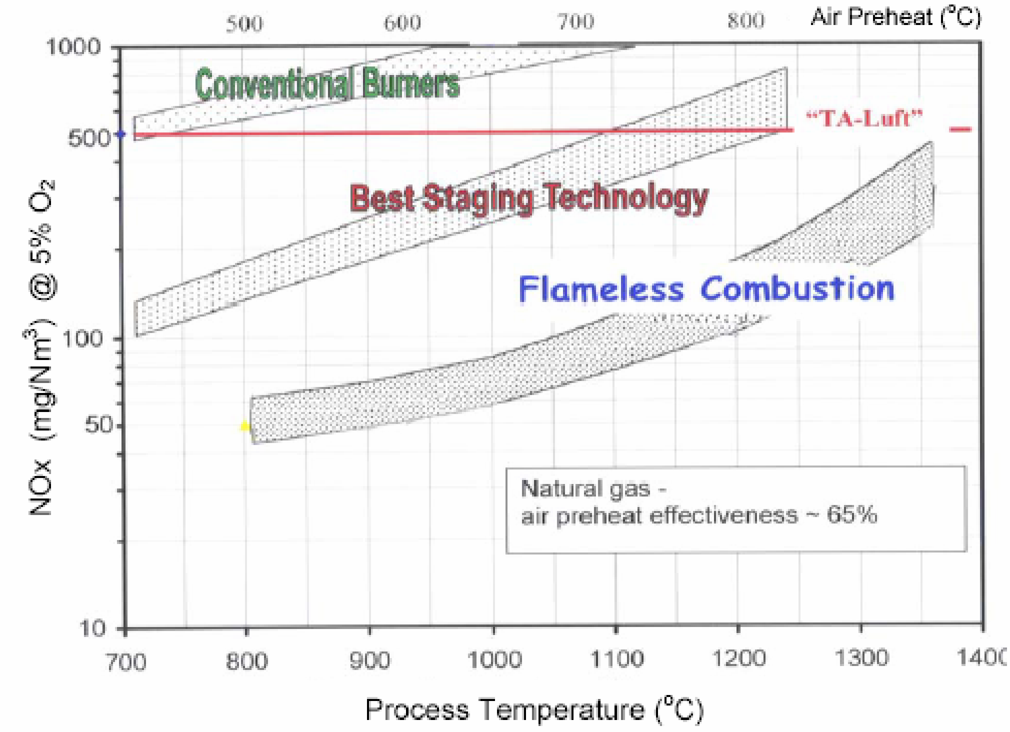

Figure 2 – NOx emissions from high temperature furnaces

injection nozzles. For example by radial injection into a primary combustion chamber, a stable flame is obtained (Figure 3a) while central gas injection prevents a flame front and makes flameless firing possible under suitable conditions (Figure 3b).

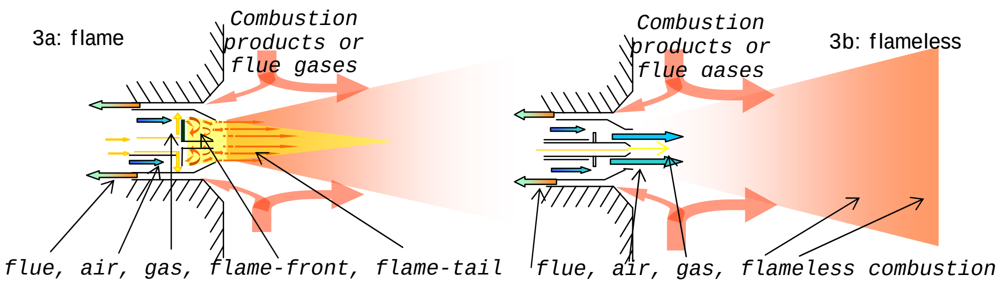

Figure 3 – High velocity burner: flame and flameless mode

Regenerative burners, designed for high temperature operation, also cope with start-up by means of multi injection systems. They consist of twin heat re-claimers or thermal capacities (capable of accumulating or yielding heat) embedded in the burner itself. Their large surface to volume ratio and the short inversion time (≈ 10 - 30 s) make it possible to reduce the volume of the regenerators. Ceramic beads or pebble beds are bulky, but honeycombs allow for a more compact design and high effectiveness of heat recovery, with air temperatures close to ~ 85-95 % of the flue gas temperature.

The auto-regenerative burner Regemat® from WS (Figure 4) has been conceived for possible substitution of existing burners. Therefore the twin ceramic beds have been embedded into a single, very compact unit instead of keeping the two units separate (common for the state of the art). The Regemat® burner designed for a nominal power of 200 kW is not much bigger than an equivalent preheated air burner. The twin thermal capacities are made of 3 ceramic cartridges connected in parallel by means of passageways in the burner body. The latter is an aluminium casting that also houses the four electro-pneumatic inversion valves, all the control solenoid-valves (for air and gas inlets), the safety switches (over-temperature, flow or pressure failure) and flow calibration devices.

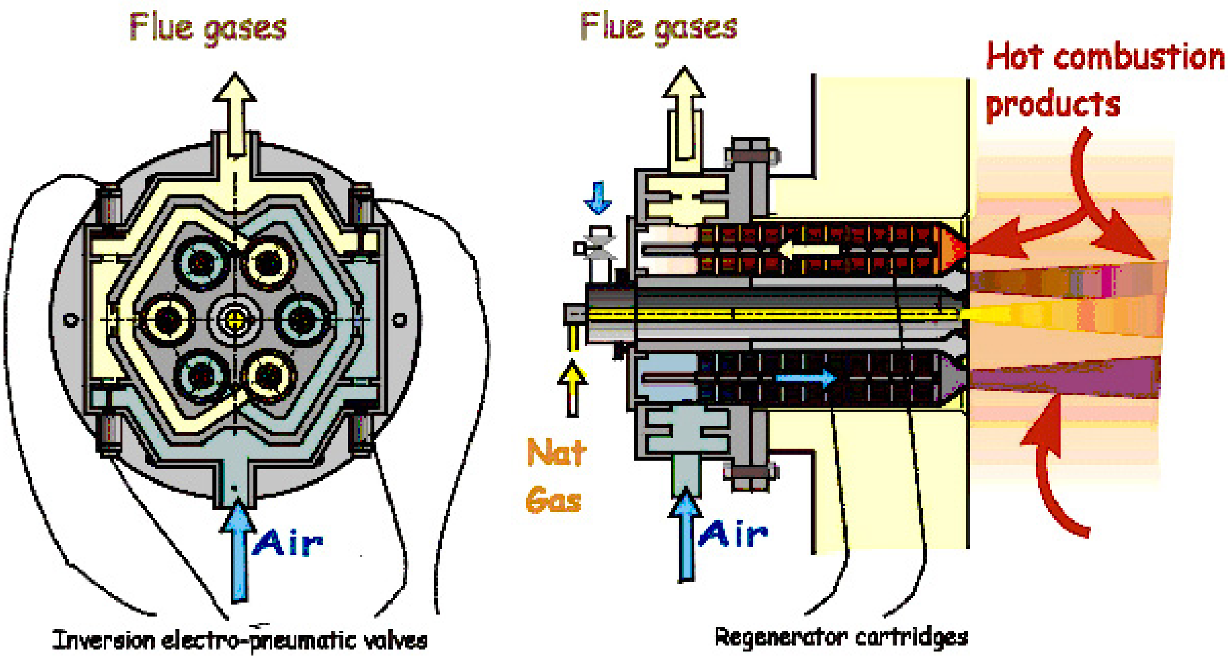

Figure 4 – Scheme of the Regemat® burner

In the schematic cross section (Figure 4), hot flue gases are being extracted from three regenerators (yellow) while cold air is introduced into the other three (blue); every 10 seconds the four valves switch to exchange the position of flue and air flow. All burners are connected in parallel to air, natural gas and flue gas manifolds; suction of flue gases requires an extraction fan that collects combustion products at a typical temperature ~120-150 °C. In the Regemat® burner, the gas is injected axially at the burner centre while the air is injected into the combustion chamber via the 3+3 Si-SiC ceramic nozzles placed around the gas injector.

For start-up, a burner-attached flame is required and this is carried out by supplying cold air to a central, high velocity burner (independently supplied). Non-preheated air and fuel are used for flame mode firing. In flame mode, each burner is monitored by its own flame detector, while FLOX® mode is only allowed over the temperature threshold monitored by a safety thermocouple. Power control of the furnace zones is straightforward. The burners are controlled “on-off” or in sequential firing and keep firing for a time interval proportional to the difference: set-point minus actual value. The flow-rates through burners are either 100% or 0 and the drawbacks of turned-down firing are avoided. All the above implies a complex control system, both on the burners (Figure 5) and in the control room; however, recent developments of digital devices and components make this task more economic and reliable.

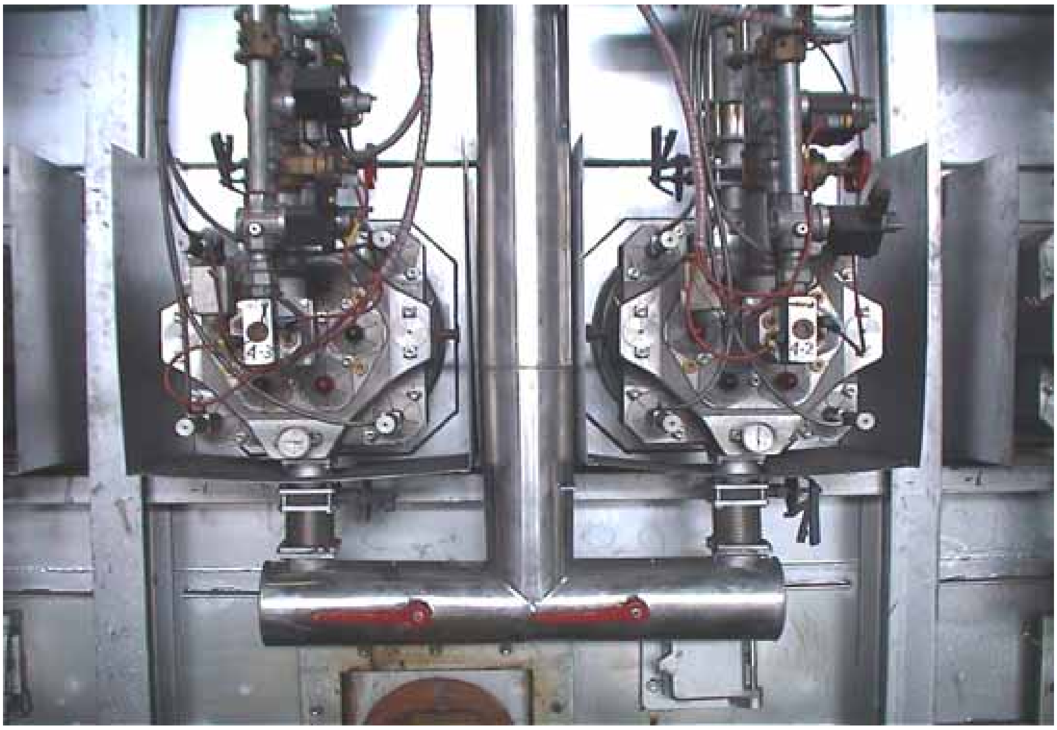

Figure 5 – Two Regemat® burners in operation

4. FIELD APPLICATIONS AND DEVELOPMENTS

The Regemat® burner has been produced and installed at demo scale after short tests of the prototype. 50 units have been installed on the revamped new zones of the annealing and pickling line for stainless strip in Terni in 1997 and have been working since that time. NOx emissions are close to ~80 mg/Nm^3 or 40-50 ppm, natural gas consumption is ~40% that of the original (cold air) plant, productivity is definitely increased and product quality is improved. There is no doubt about the potential advantages of the new combustion system [4]. Maintenance requires more care than traditional equipment, but the first series of Regemat®

burners are still working with only a limited number of units being seriously damaged and replaced after 7 years service.

Following the success of the European Thermie demonstration project [4], the Commission also supported a dissemination project aimed at promoting the new technology, in other industrial high temperature processes [7]. Regemat® burners have been installed on several laboratory furnaces in academic or R&D centres all over Europe, to be characterized and tested.

The design of the Regemat® burner itself has been improved with respect to the first series, improving the hot end with Si-SiC ceramic, and minor changes to the on-board devices. Also it is possible to fire the central start-up burner while in FLOX® mode by firing in parallel. The power input is greatly increased (though with an overall penalty in efficiency), which may be useful for emergency peak demand.

Quite a few possibilities were investigated for adapting the technology to several industrial processes and significant developments are now being designed and tested. This usually involves new pieces of equipment designed for special applications [8]. The regenerative burner is not intended for use in reducing conditions in the combustion chamber; however, measures can be taken for occasional, safe firing below stoichiometric conditions.

5. ANNEALING AND PICKLING LINES

These improved Regemat® burners have been recently used to equip other annealing and pickling lines for stainless steel strip (mainly austenitic, AISI 300 series), similar to the Terni plant. This was done to obtain the following advantages summarized in the list ensuing from the first demo project Thermie [2,4]:

- NOx emissions ~ 40-60 ppm (from ~ 150-300 ppm)
- natural gas consumption ~ 30 Nm^3/tonne (from ~ >35 Nm^3/tonne)
- productivity increase ~ 25 % (same furnace length)
- improved strip temperature uniformity
- competitive specific investment cost per unit production

The figures in the above list show a comparison with a conventional solution employing a central heat exchanger at the chimney for preheating the air and a passive zone at the furnace inlet, as this is the state of the art. If the benefit in productivity is taken into account (increased tonnage from the same furnace length), then the investment cost per t/h of treated steel is competitive even without taking into account the reduction of the fuel bill (~ 10 – 20% or more).

The first A&P line [3] has been completely built from green field and includes a 60 m long furnace (Figure 6) fired with ~90 Regemat® burners. The performance of the new plant, which has been operating for a couple of years, is excellent with respect to product quality, efficiency and emissions. With the automated operation, a team of 5 operators per shift can manage production in this large furnace. A more recent application, still in commissioning stage, concerns the revamping of the existing furnace in an A&P line, for austenitic stainless steel strip in South Africa. The existing, large, concentrated regenerative burners in the preheat zone did not perform satisfactorily because of maintenance problems, but even more because they were not able to exploit the benefits of decentralised, burner-integrated heat recovery mentioned above. In this case the productivity increase obtained with the new technology has been the decisive factor and new Regemat® burners have equipped the preheat zone, while retrofitting of other zones will follow shortly.

Figure 6 – Inside and outside view of the A&P Line (courtesy of KTN [3])

6. CONCLUSIONS

Thanks to proven industrial applications, new, advanced, high-temperature firing equipment can be used at no risk in continuous A&P lines for stainless steel strip.

The new technology is also more convenient, when taking into account that larger initial investment in more sophisticated equipment can be compensated in a short pay-back time, not only by energy savings and reduced emissions, but also by improved product quality and more reliable operation of the whole plant.

Introduction of compact regenerative burners, developed for the purpose, has introduced a consistent step forward in the furnace concept. This spin-off, that is from a piece of equipment to the plant/process, is welcome and can bring about future significant advancements in the technology of strip line annealing furnaces and of similar high temperature processes.

7. REFERENCES

[1] Wünning J.A. and Wünning J.G.. (2001). **Ten Years of Flameless Oxidation: Technical Applications and Potentials** - *4th International Symposium on HTACG - High Air Temperature Combustion and Gasification* – Rome, November 2001.

[2] Milani A., Salamone G., Wünning J.G. (1997). **Low NOx-Regenerativbrenner in einer Anlage zum kontinuierlichen Gluhen von Edelstahlband** – *Gas Wärme Int.*, Vol. #46, H12 pp. 606-612.

[3] **ThyssenKrupp Nirosta nimmt neue Kaltbandlinie in Betrieb** – *Stahl Eisen.* 123, 9, September 2003

[4] Milani A. (1998). **Abatement of Fuel Consumption with Compact Regenerative Burners in Energy Intensive Furnaces** - Final Report EC Thermie Project IN15/95/IT/DE.

[5] Flamme, M.; Brune, M., Konold, U., Al-Halbouni, A., Scherello A., Giese, R. (2001). **Optimization Of The Energy Efficiency Of Industrial Furnaces (ETA)** - *4th International Symposium on HTACG - High Air Temperature Combustion and Gasification* – Rome, November 2001.

[6] International Flame Research Foundation. (2002) **Combustion Files 171 –175 and 214-216**. IFRF Combustion Handbook. http://www.handbook.ifrf.net

[7] Thermie Programme (2001). **Dissemination of Advanced Combustion Technology for High Temperature Processes with Focus On SMEs** - *Thermie B contract SME/1891/98/DE, Final Report.*

[8] Wünning J.G. (2003). FLOX® - **Flameless Combustion** – *Thermprocess Symposium*, Düsseldorf, May 2003.