Thermoprozess- und Abfalltechnik

VDMA

Themenblock 1:
Beheizung

THERM® PROCESS

"FLOX® – Flameless Combustion"

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Dieser Artikel liegt nur in englischer Sprache vor.

Thermprocess Symposium 2003

VOLLKERAMISCHER BRENNER UND
VOLLKERAMISCHES STRAHLHEIZROHR
▶ HOHER WIRKUNGSGRAD
▶ ANWENDUNGSTEMPERATUR BIS 1250°C
▶ WENIG NO_x
Bitte besuchen Sie uns:
Thermprocess, Düsseldorf
16.-21. Juni 2003
Halle 5, Stand 5 H 35
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Flox® - Flameless combustion

1 Introduction

If a combustible mixture of fuel and air is ignited, a flame can develop. In the reaction zone, called flame front, the temperature rises quickly to temperatures close to the adiabatic temperature. The flame can be stabilized within or close to the burner, so that the combustion goes stable and controlled. The different methods for flame stabilization play an important role in the field of burner development. Examples are baffle and swirl stabilization.

For the required flame supervision, optical and electrical effects of flames are used. Modern burner designs use UV or ionisation detectors for automatic flame safety systems. In the absence of a flame signal, the burner is shut off. Therefore it can be said, that flames fullfill two important functions:

- flame stabilisation guarantees a constant and controlled reaction
- and a stable flame provides a steady reliable signal for flame safety systems.

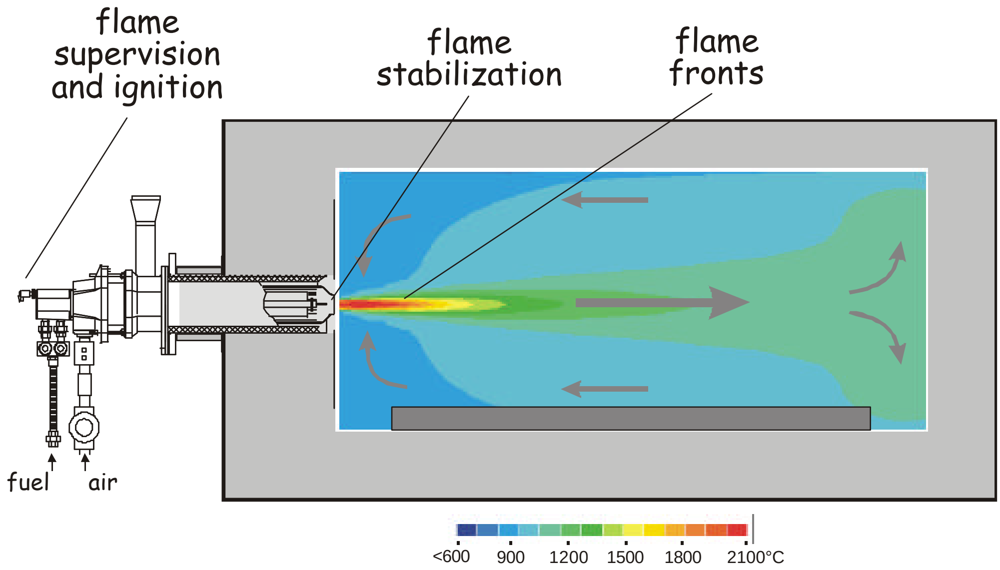


Figure 1: main characteristics of flames

The question is why to give up the proven concept of flames and what are the advantages of flameless oxidation. The main important answer to this question is that flameless oxidation can suppress thermal NO-formation even when highly preheated air is used.

The presentation will provide an overview of the activities around flameless oxidation from the last decade and it will also give an outlook on future potentials.

2 Using Preheated Air for Combustion

Following the first and second energy crisis in the seventies and early eighties, many R&D activities focussed on the improvement of energy efficiency. The most effective method for improving efficiency of combustion systems, used for high temperature processes, is combustion air preheating. Central recuperators reach air preheat temperatures of up to 600°C. Decentralized air preheat systems allow for much higher figures. Since the air preheat temperature increases approximately linear with the process temperature, the efficiency of combustion systems can be shown in a clearly arranged diagram.

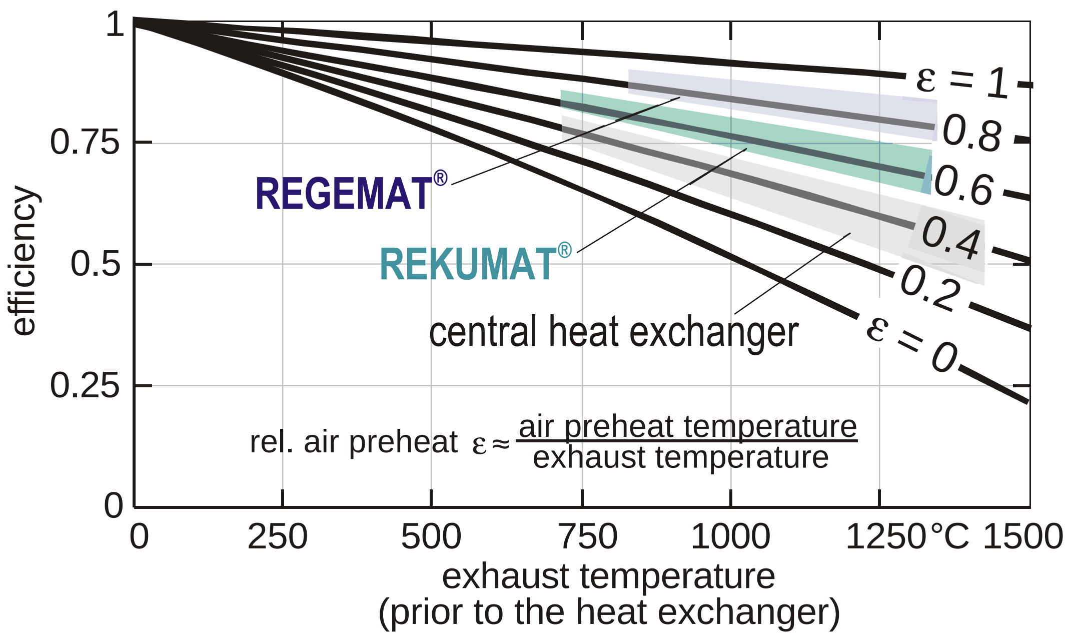


Figure 2: efficiency

During the same period, the awareness of the negative effects of NO_x-emissions on human health and the environment put growing pressure on operators and producers of combustion equipment. While NO_x-emissions were abated with secondary measures in some technical sectors, e.g. catalytic converters in automobiles, the thermal process industry developed and used widely primary measures like staging (see Figure 3). Using these NO_x-reduction techniques, emission standards like the German TA-Luft could be met for process temperatures up to 1200°C and relative air preheat of 0.6 (~700°C). To meet more rigid existing or future limits as well as to apply higher air preheat temperatures was not possible.

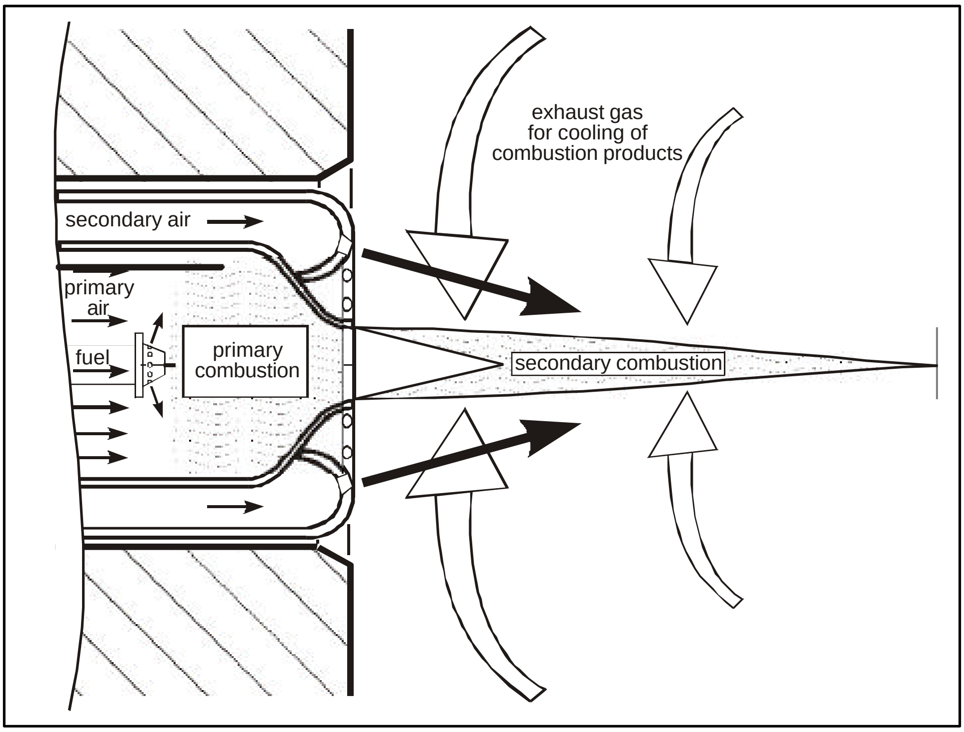


Figure 3: burner nozzle of an air staged high velocity burner

3 Fire without Flame

In 1989, a surprising phenomenon was observed during experiments with a self recuperative burner. At furnace temperatures of 1000°C and about 650°C air preheat temperature, no flame could be seen and no UV-signal could be detected. Despite that, the fuel was completely burnt. The carbon-monoxide content in the exhaust was below 1ppm. The NO_x emissions were close to zero, in the single digits, what was first thought to be a malfunction of the NO-analyser. The combustion was stable and smooth, there was no lifted flame.

We called that condition flameless oxidation of short FLOX®[1].

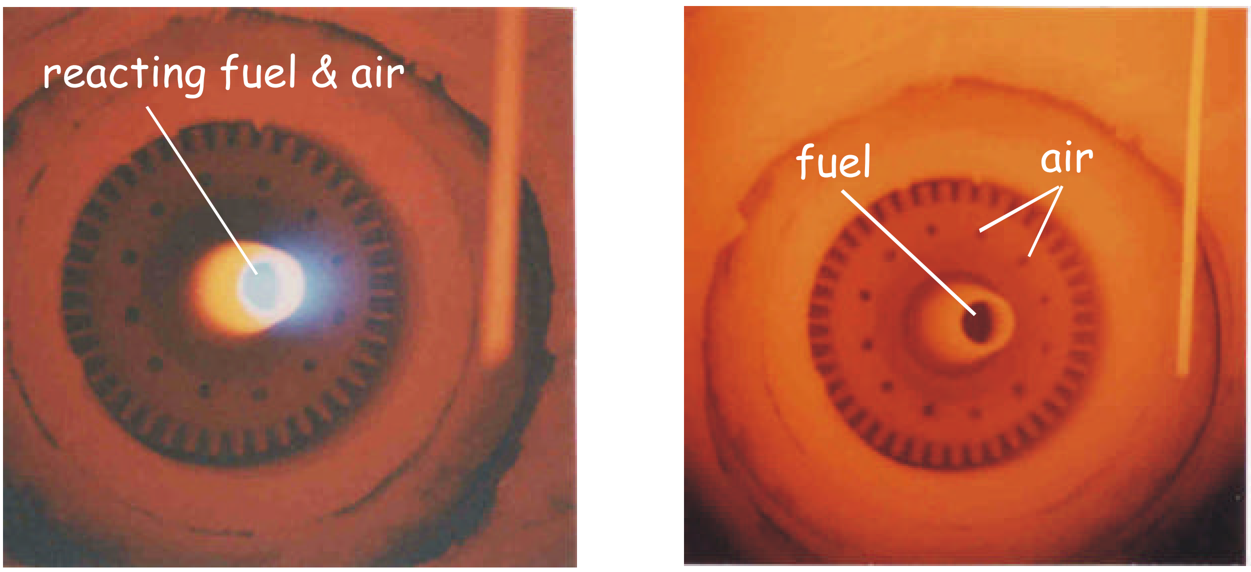


Figure 4: Flame and FLOX®

Further experiments were carried out to determine the essential conditions for FLOX®. Fuel and air jets have to be mixed into a strong recirculating flow of exhaust prior to reaction. Then, no flames and therefore no high temperature peaks occur[i]. Air preheat is not a prerequisite for flameless oxidation. The technique of flameless oxidation was patented worldwide [ii].

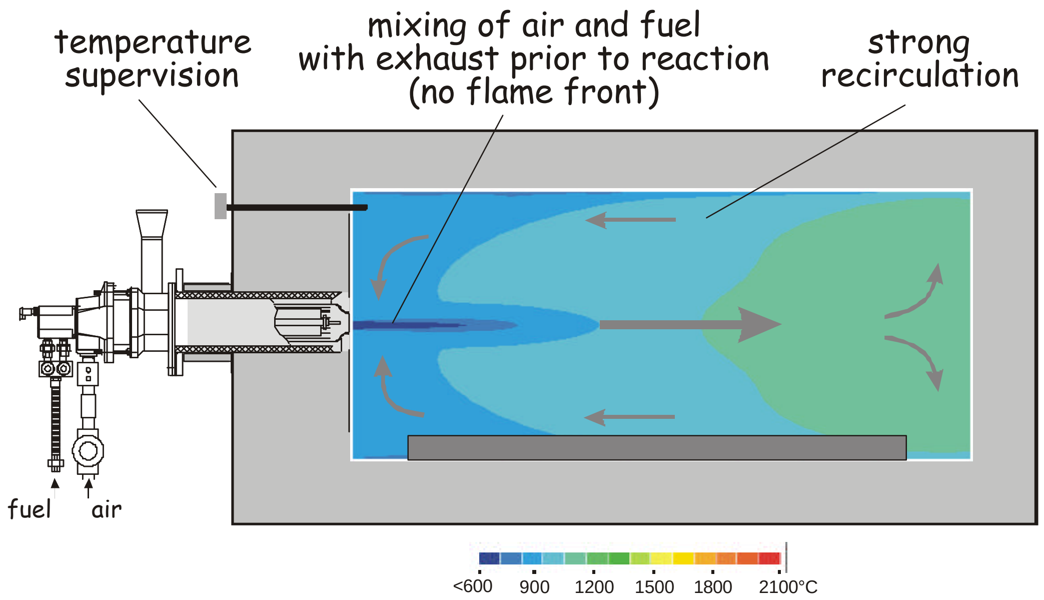


Figure 5: main characteristics of flameless oxidation

4 Investigating the basics

While the first FLOX® burners were developed and the first commercial burner was sold in 1991, R&D programs wee set up to investigate the fundamentals of flameless oxidation[iii iv v].

Similar to flame combustion, areas of stable combustion for flameless oxidation can be described. In between these areas, unstable and lifted flames occur which are not suitable for technical combustion.

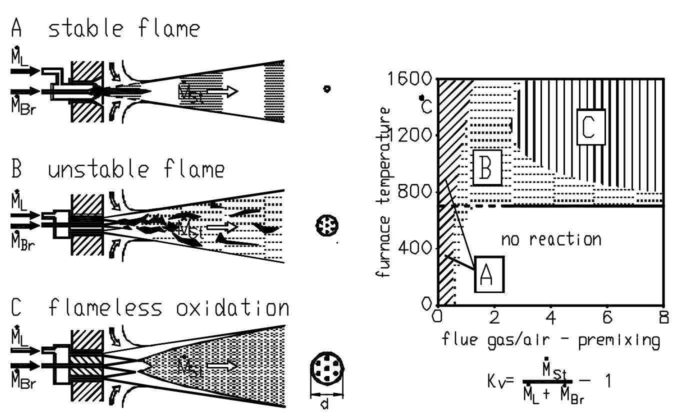


Figure 6: stability limits

It was found that it is possible to produce highly visible areas with flameless oxidation when conditions allowed fuel to pyrolise in low oxygen areas to produce shining soot particles.

During this period, commercial CFD codes (Computational Fluid Dynamics) became available to run on workstations or PC's. The suitability of CFD codes to simulate flameless oxidation was part of a R&D project, funded by the German Ministry of Education and Research. A test furnace was designed and built to study flameless oxidation and to provide data sets for comparison with result from computer simulations. A recuperative burner was firing bottom-up into a cylindrical furnace, minimizing buoyancy effects. The furnace was equipped with air cooled tubes which were arranged concentric along the furnace wall. Air cooling, in contrast to water cooling, allows for adjustable cooling and make it possible to adjust the furnace temperature widely independent from the burner capacity. The air preheat temperature was adjusted by controlling the amount of exhaust flow, bypassing the recuperator. The non-cooled probe was inserted from the top and could be positioned fully automatic throughout almost the whole furnace. Data collection for several hundred positions in the furnace was possible in about one hour. The probe was equipped to measure temperature, using a 50 µm PtRh Pt thermocouple, pressure and gas samples.

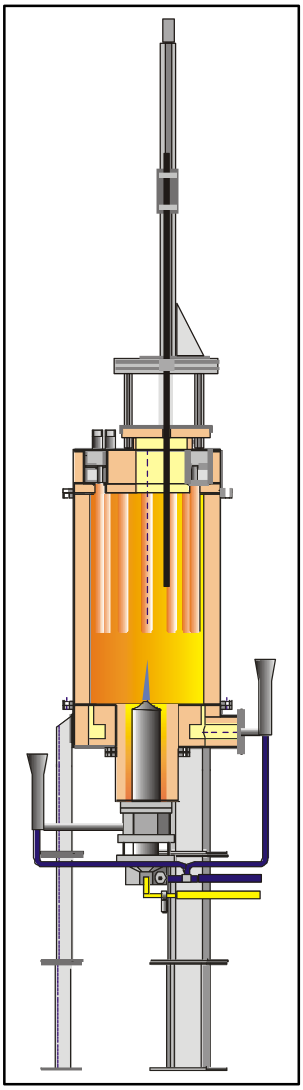


Figure 7: experimental furnace

Figure 8 shows temperatures from a fixed position, 250 mm away from the burner. NO_x was measured in the exhaust. The burner was operated in flame, lifted flame and FLOX® mode. Flame and flameless oxidation mode show steady temperature conditions. NO_x and noise are substantially higher in flame mode, compared to FLOX® mode. NO_x and noise are inbetween for the lifted flame but the temperature signal is highly unstable.

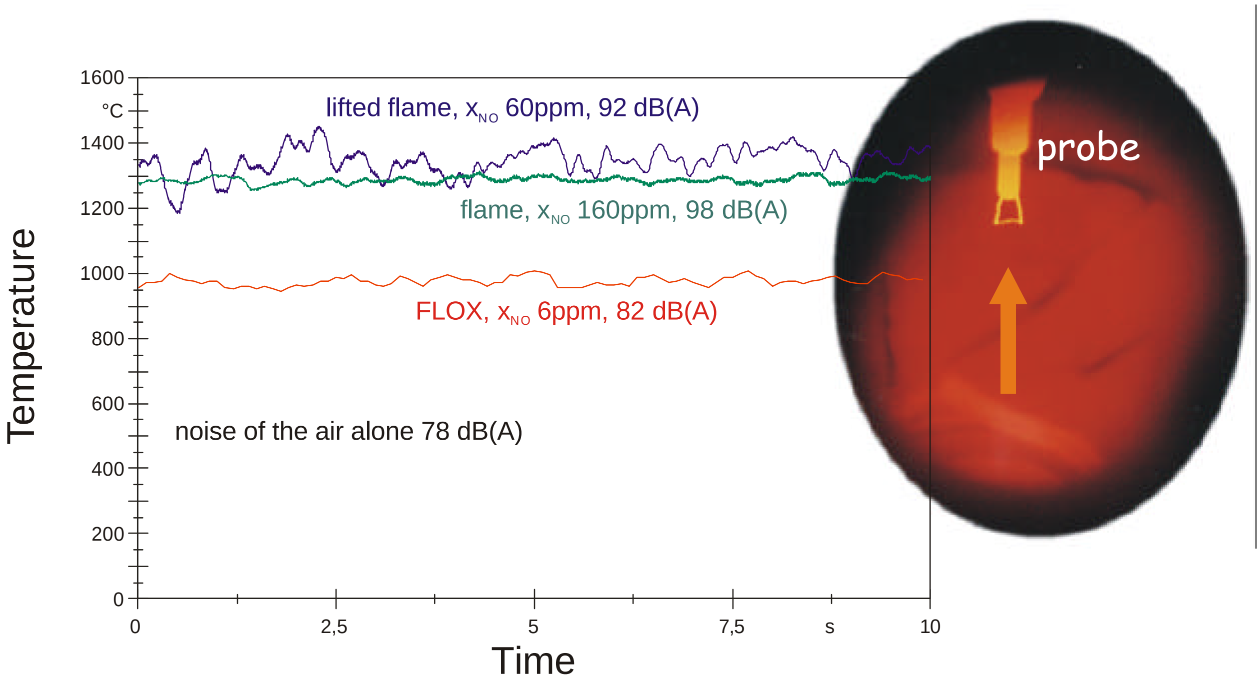


Figure 8: time resolved temperature measurement for FLOX®, flame and lifted flame

Figure 9 shows temperature fields for FLOX® and flame operation. Clearly visible is the different characteristics of the temperature field. High temperature close to the burner nozzle in flame operation (temperature measurements were limited by the thermocouple temperature range), low temperatures in FLOX® mode.

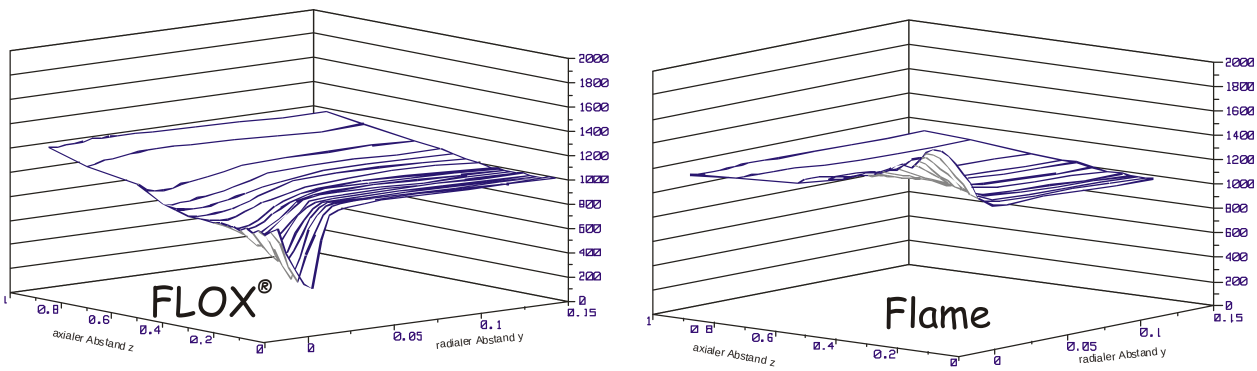
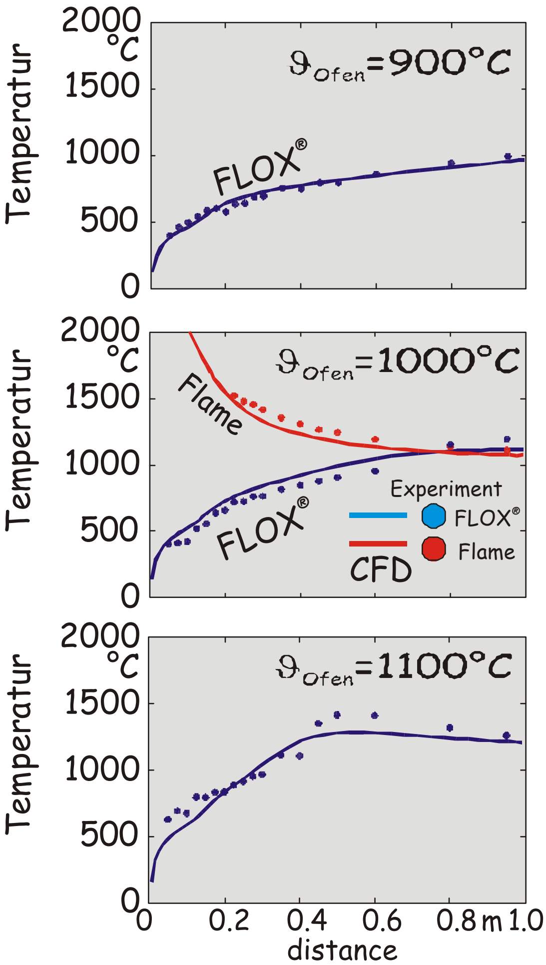


Figure 9: measured temperature fields of FLOX® and flame operation



After determine the suitable sub models and constants for the CFD calculations, the data

Figure 10: comparison of experiment and model

from the computer simulation and the experiments were compared. The results showed good agreement over wide range of parameter variations except changing the fuel. The predictions of NO_x predictions were qualitatively and on a technical level satisfying. This allowed for parameter variations (see figure 11) to be calculated in a fraction of time and costs, compared to experiments.

This kind of fundamental investigations were continued by WS GmbH and a number of research groups to the present [vi vii viii ix]. One example in figure 12 shows data obtained by laser measurements techniques [x].

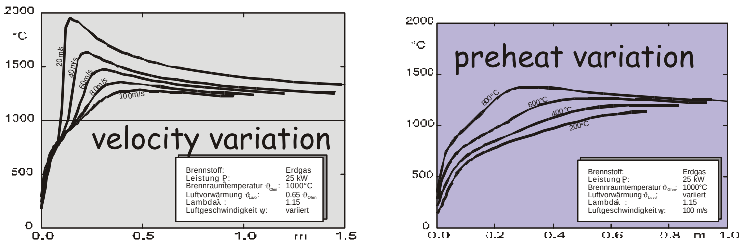


Figure 11: CFD parameter variations

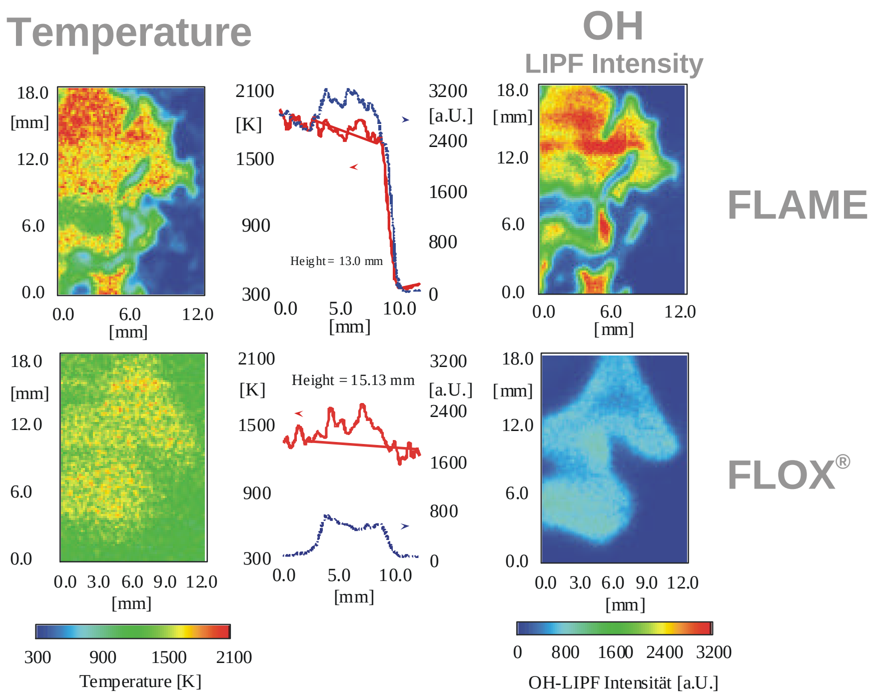


Figure 12: temperature and OH data obatained by laser measurement techniques

Further research will enable predictions of flameless oxidation for a wide range of gaseous, liquid and solid fuels in a wide variety of set-ups as well as improved predictions on emissions.

Among others, one very important result of the investigations was, that it is not necessary to inject fuel and oxidant separately into the furnace. While the "mixed is burnt" approach was used in the beginning, more knowledge about the reaction kinetics allowed for a simultaneous mixture of fuel, air and exhaust, suppressing reaction by slow kinetics. This lead to new patented burner designs, called "one-nozzle" FLOX® burners [xi].

5 Exploitation

While the first recuperative and regenerative FLOX® burners were installed during the early nineties, several FLOX® burner designs became a regular serial product for a variety of applications. Most of the burners were installed in heating and heat treating furnaces of the metal and steel industry[xii] [xiii]. Several projects were carried out which were aiming to develop new burner designs or to investigate the effects of applying flameless oxidation to certain processes.

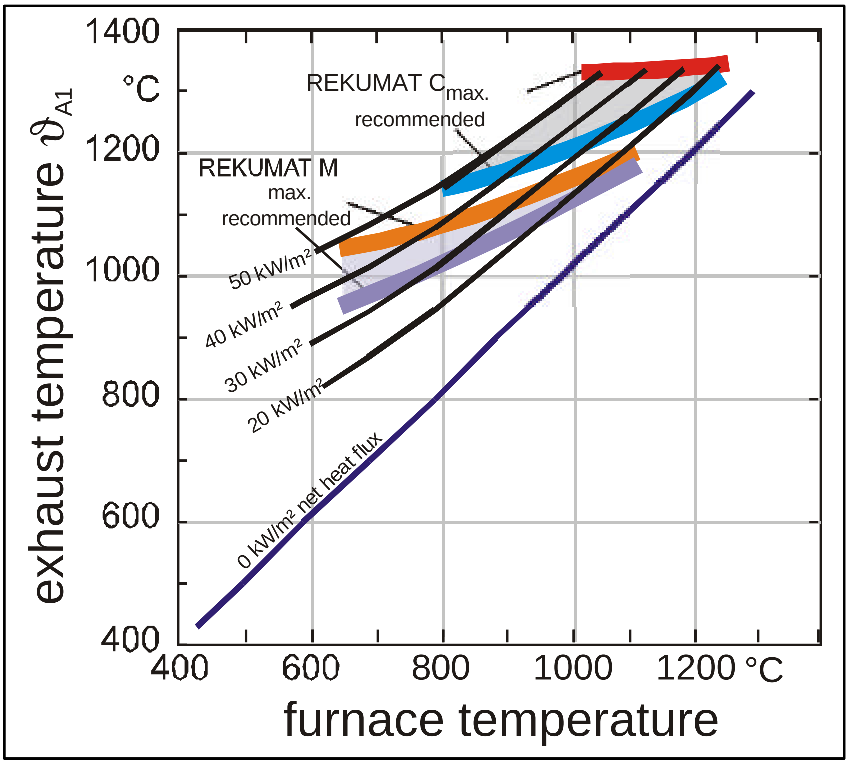


Figure 13: exhaust gas temperatures in radiant tubes

One of the R&D projects focused on the development of ceramic recuperative burners and radiant tubes[xiv]. In radiant tubes, and more so in ceramic radiant tubes, efficiency and NO_x is an important issue since internal temperatures in radiant tubes are substantially higher then the process temperature. A breakthrough was the installation of several hundred ceramic radiant tubes and FLOX® burners in a silicon steel strip line (see Figure 14) in 1994. Up to now, several thousand ceramic burners and radiant tubes are installed [xv]. While first designed for high temperature applications to replace electric heating and short living metallic radiant tubes, ceramic radiant tubes were used more and more in lower temperature processes, providing approximately double the heat flux, compared to metallic tubes.

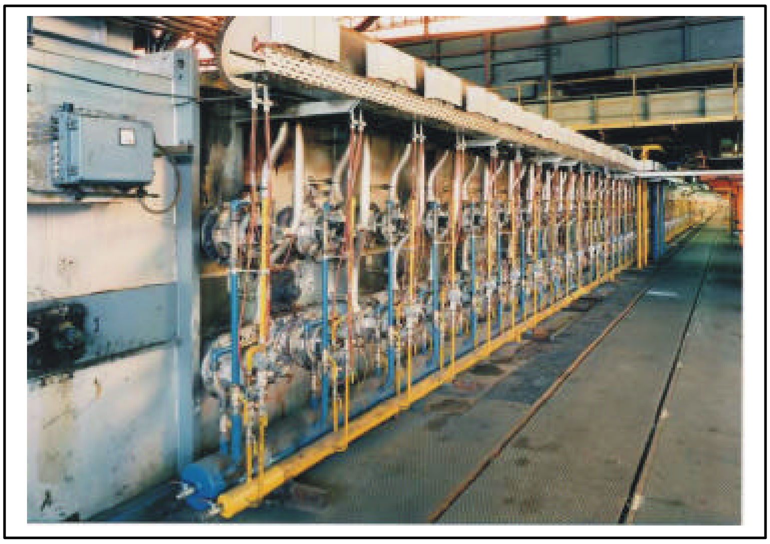


Figure 14: silicon steel strip line

The latest improvement is a special inner tube for FLOX® fired single ended radiant tubes. The special shape of the inner tube enhances recirculation for minimum NOx-emissions. (see Figure 15).

Figure 15: new inner tube design

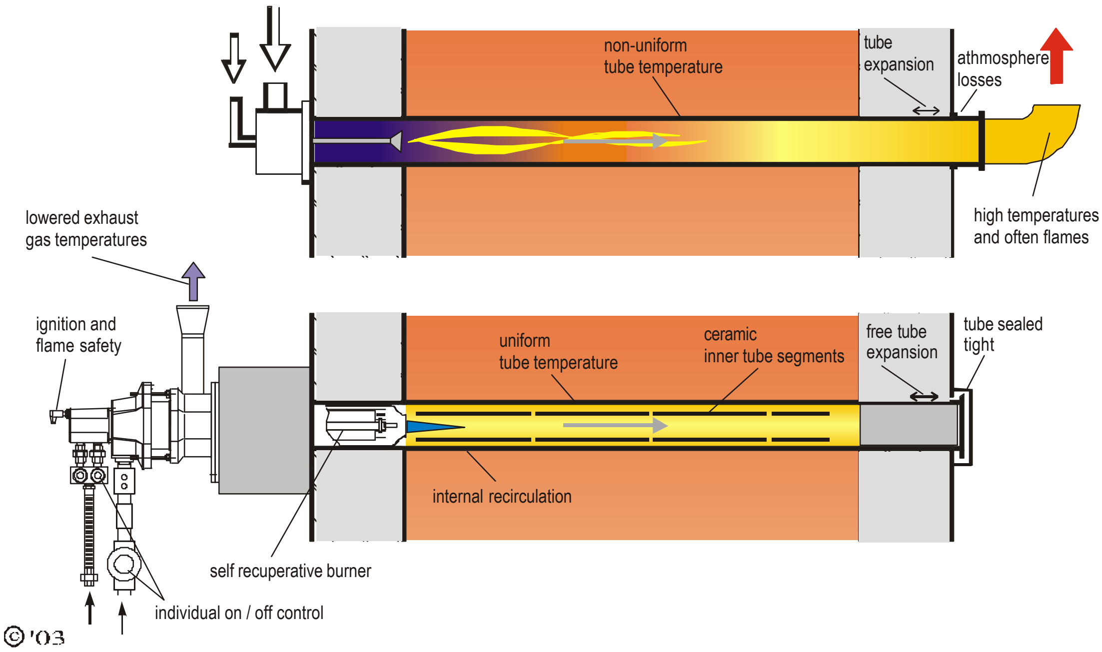


Figure 16: retrofitting straight through tubes to recuperative single ended tubes

Figure 16 shows a retrofit project where an old straight tube was reused for the conversion to a self recuperative FLOX® burner. This solution was choosen to keep costs and furnace downtime at a minimum. Energy savings of well over 40% were achieved while improving temperature uniformity and tube life and eliminating athmosphere losses.

Another focus is the development of radiant tubes for vertical strip lines. So far, W-tubes were most commonly used for these kind of applications. In 2001 the new galvanizing line at TKS, Dortmund (Figure 17) was equipped with Double-P-Tubes.

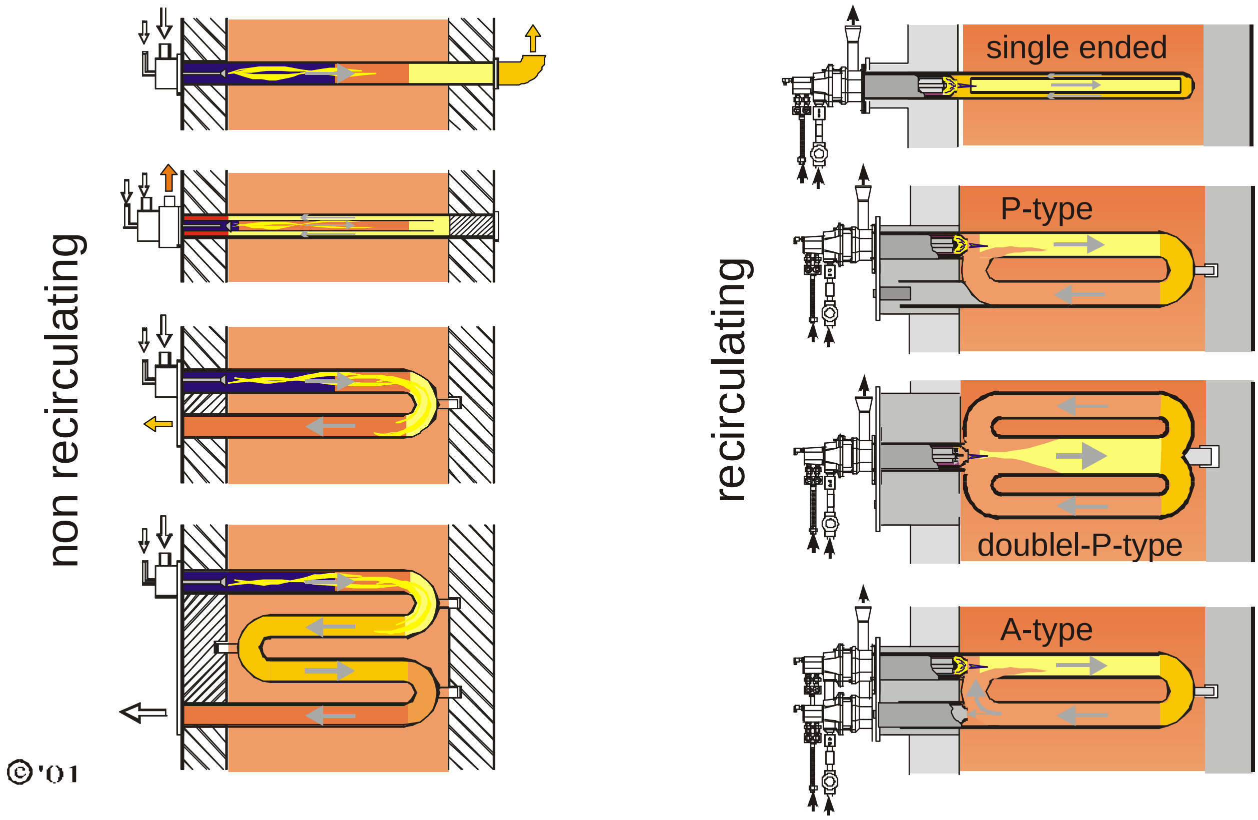


Figure 17: radiant tube design

The surface area of a double-P-tube (see Figure 15) is comparable to a W-tube, having larger diameter legs. The recirculating design provides a greatly improved temperature uniformity. Since there is only one radiant tube leg breaking through the furnace wall, there is no need for a compensator or a sliding connection. The efficiency of a self recuperative burner is superior to plug in recuperator, raising the fuel efficiency. The lower exhaust temperatures help to keep the surrounding of the furnace cooler, often a problem, espacially on the upper decks of a vertical furnace. The internal recirculation is a requirement for FLOX® operation, necessary to keep in compliance with current and future strict NO_x standards.

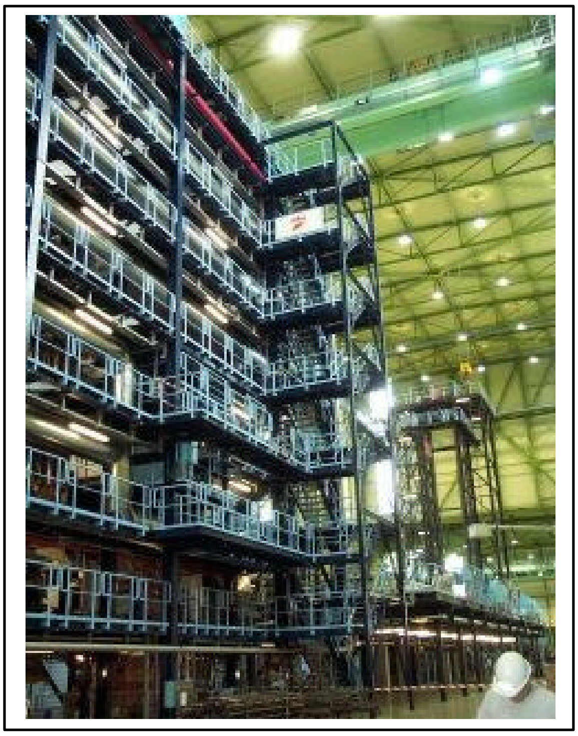


Figure 18: vertical strip line

In 1995, a EC funded project started to demonstrate the potentials of a new compact regenerative burner design. The burner uses ceramic honeycomb regenerators which are integrated into the burner.

Figure 19: annealing and pickling line in Terni

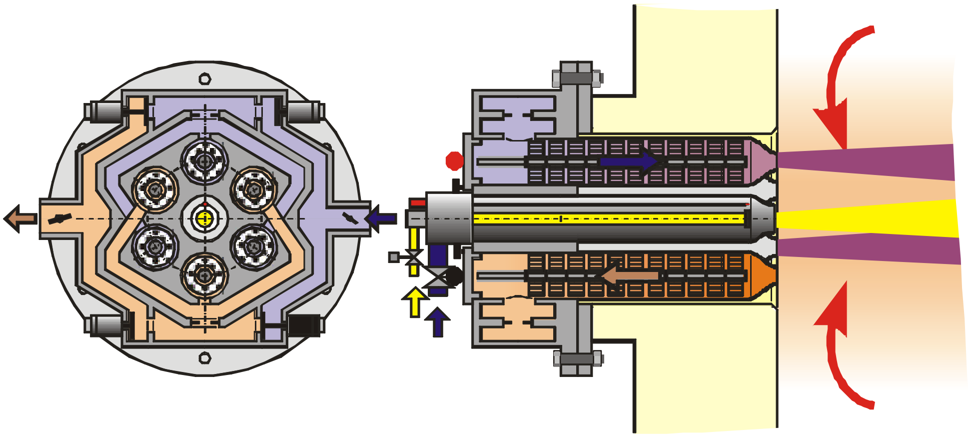


Figure 20: self regenerative burner

Figure 19 shows installed regenerative burners in an annealing and pickling line. The specific energy consumption of the furnace was cut in half while the production capacity was increased considerably. NO_x-levels are considerably below 100ppm [xvi].

To be prepared for rising energy prices, WS started the development of a new regenerative radiant tube system, called A-tube. Thermal efficiency of more than 80% is possible using a regenerative system with ceramic honeycomb regenerator media. After successful lab tests, one burner was installed in a galvanizing line. The performance regarding efficiency and NOx-emissions are excellent. The system will be thoroughly tested and improved prior to extensive installations to avoid problems which have been experienced with regenerative radiant tube systems in the past.

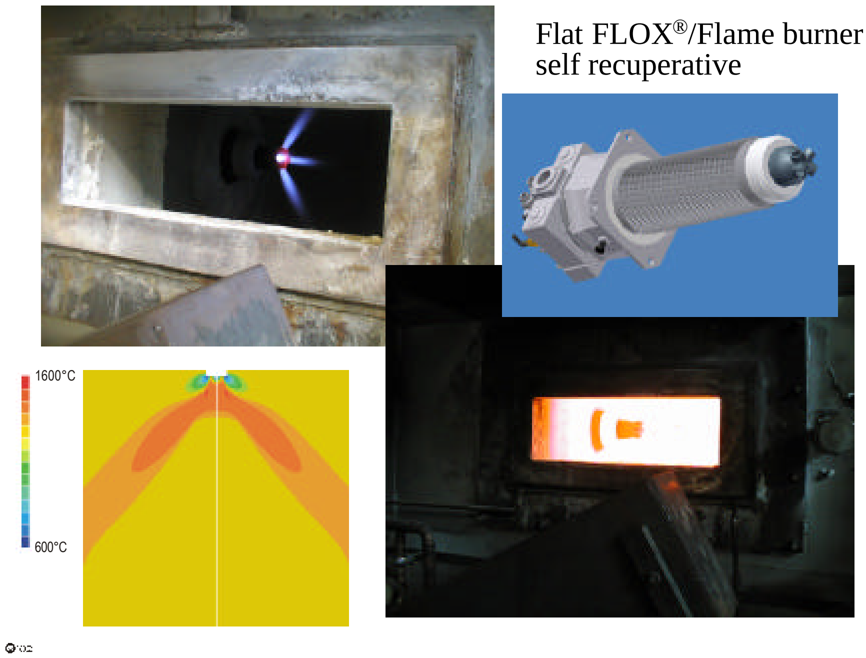


Figure 21: Flat Flame FLOX® burner

Flat flame burners are often used to avoid flame impingement in situations, where the load is arranged in front of the burner. A special nozzle allows for a wide variety of arrangents including the typical arrangement of flat flame burners.

Integrated heat exchangers of self regenerative or recuperative burners are often superior to central heat exchangers, but there are application where they cannot be used. Examples are dusty furnace athmospheres zones with substoichiometric combustion. There are also retroffit projects where it is more economical to keep an existing heat exchanger. To take advantage of the FLOX® concepts for these applications, a FLOX® hot air burner is available now.

6 Other R&D Activities

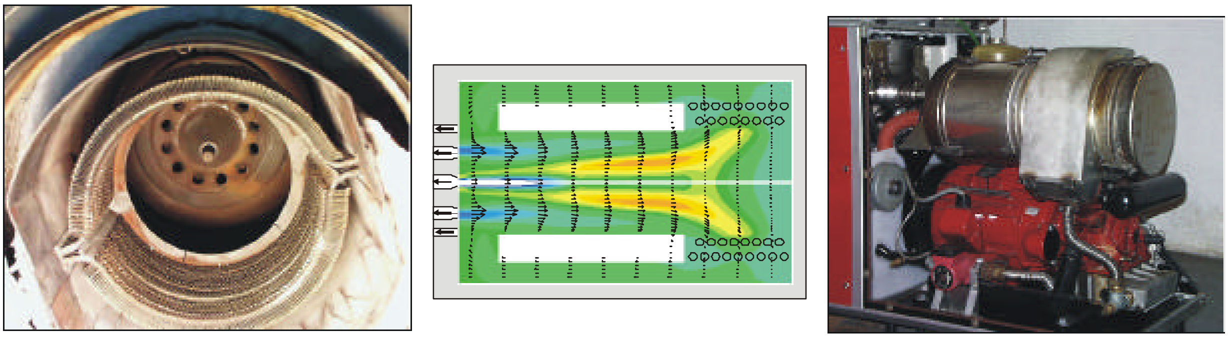


Figure 22: burner development for stirling engines

Besides application in the steel and ceramic industry, other applications for FLOX® were investigated in a number of research projects. One was, to develop FLOX® burners for Stirling engines. Besides low NO_x-emissions and high efficiency, a compact design and the potential for low production cost, when produced in large series, were important. The Stirling engines are intended to be used as CHP-units (combined heat and power) for decentralized electric power generation.

NO_x-emissions from glass melting tanks are very high due to very high process temperatures. It was not clear whether FLOX® could provide NO-levels, meeting future regulations. A R&D project, carried out with a research institute and a glass manufacturer should investigate this possibility. Results were promising but so far, no furnace was retrofitted due to the high costs and the unknown influence on glass quality. Results from a smaller glass furnace for melting cullet were very positive, but there lower temperatures of only 1300°C are required.

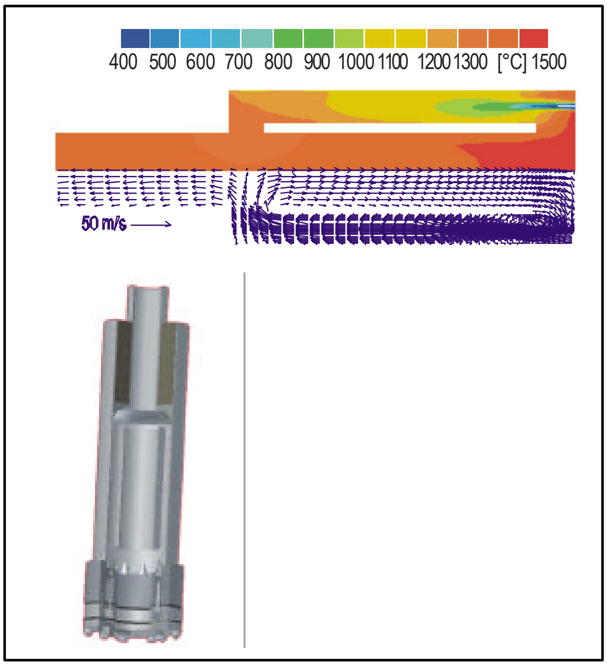


Figure 23: FLOX® gas turbine combustor

Gas turbine combustors are operated under very specific conditions. Very high combustion densities are common and extremely low NOx emissions are required. Prototype tests were very promising with NOx emissions in the single digit and even below single digit range.

Recent experiments (RWTH Aachen, WÜK, Prof. Renz) show that it is possible to achieve flameless combustion even with solid fuels like coal dust.

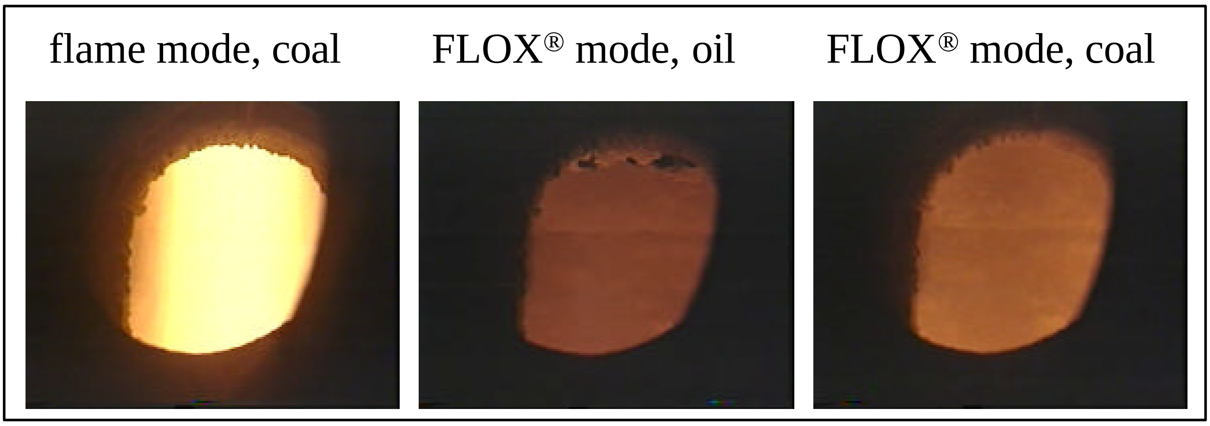


Figure 24: FLOX® using different fuels

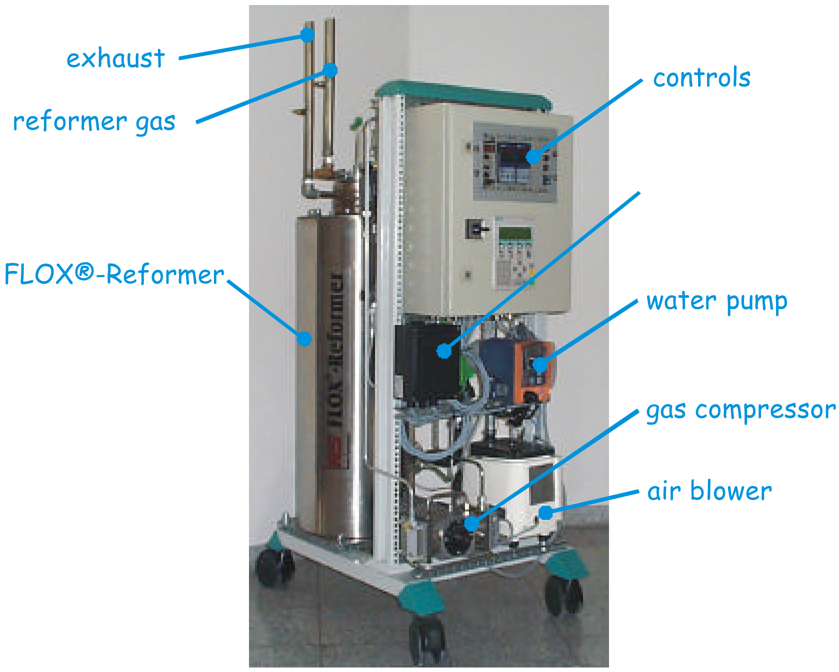
Lots of activities have started to exploit the benefits of flameless combustion for reforming processes, especially the steam reforming process to generate hydrogen in small, medium and large plants. Low NO and the uniform temperature field are ideal for these processes.

7 Today and Tomorrow

Up to now, many thousand FLOX® burners were installed in different applications. Often, the reduced NO_x-emissions were the motivation to apply flameless oxidation, but in many cases:

- more homogenous temperature distribution
- reduced thermal stress for the burner
- reduced noise
- less burner faults
- less restrictions on fuels because no flame stability is required

were also important factors. Development will continue to improve recuperative and regenerative burners. Rising energy costs will favour regenerative concepts due to their higher potential for efficiency. Currently, regenerative radiant tubes which allow for internal recirculation, called A-type-tubes, are under development.



FLOX®*- Reformer in a test rig

Figure 25: FLOX® reformer furnace concept

Concepts were developed for:

- petrochemical furnaces (reformer)
- micro FLOX®-reformers for fuel cells
- gas turbine combustion chambers
- waste gas disposal

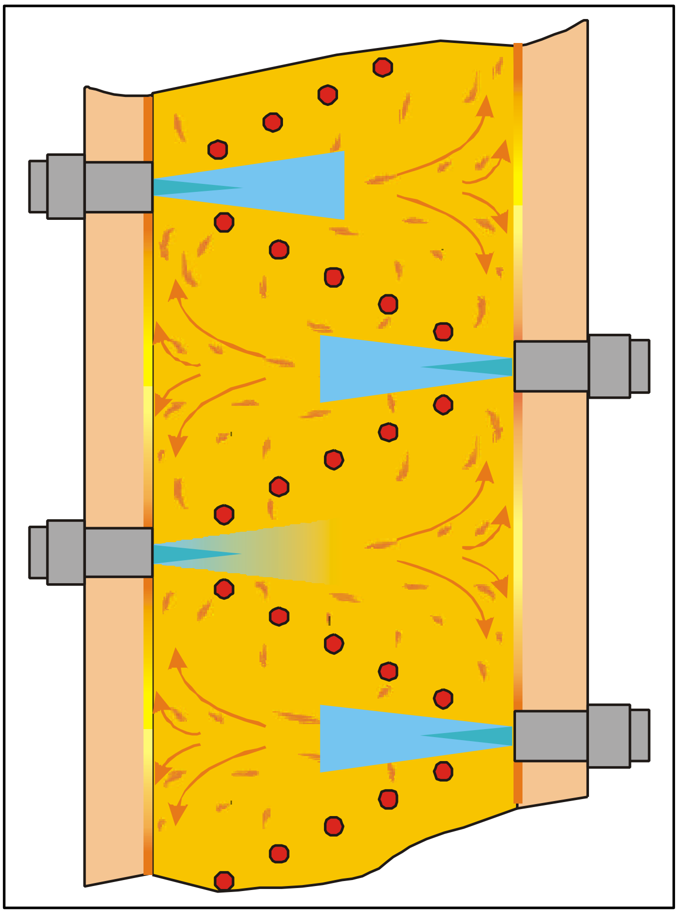


Figure 26: FLOX® reformer in a test rig

For some burner designs, licences were granted and further licences will be offered to enable other companies or research groups to use the potential of flameless oxidation on a wide variety of applications.

8 Literature

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