projektinfo 07/06

BINE Informationsdienst

Flameless combustion

- Energy savings from utilisation of exhaust gas heat
- New applications for proven technology
- Decentralised hydrogen production from natural gas
- Coal dust combustion low in harmful substances
- New possibilities for utilisation of lean gas

Fig. 1

Ceramic radiant tube in test laboratory

What at first sounds like a paradox – flameless combustion – is being implemented in an increasing number of industrial high temperature burners. With a sophisticated mixture of combustion gas, combustion air, and recirculating exhaust gas, it is possible, with so-called FLOX® burners, to maintain combustion without flame. The decisive advantage is that even with high furnace temperatures, almost no nitrogen oxide is formed. The process also enables efficient utilisation of fuels, as the exhaust gases can be used for preheating the combustion air.

The nitrogen oxide emissions alone represent a significant challenge in high temperature processes. Often, the threshold values defined in the German Technical Instructions on Air Quality Control (TA Luft) can only be achieved with costly downstream purification of the exhaust gases. Atmospheric nitrogen oxidises to a notable extent in the hot zones of the flame front. In flameless combustion, these temperature peaks do not occur, and a constant furnace temperature of up to around 1,400 °C can be maintained with low nitrogen emissions.

Thus, it is no surprise that now, 15 years after the first commercial FLOX® burner was commissioned, there are many varieties available, for a broad range of applications. This technology is used especially in the steel industry and in burners for heat treatment.

The potential of FLOX® technology is, however, far from exhausted. Various projects, some of which sponsored by the German Federal Ministry of Economics and Technology (BMWi) and the European Union, are exploring the utilisation of lean gases and biofuels, power plant technology, and combined heat and power generation. Devices using FLOX® technology have also been developed for the reformation of natural gas to hydrogen. Compared to burners with no preheating, it is thus possible to reduce the fuel consumption by up to 50%.

► How do FLOX® burners work?

Fig. 2: Starting the burner in flame operation (a) and FLOX® operation (b)

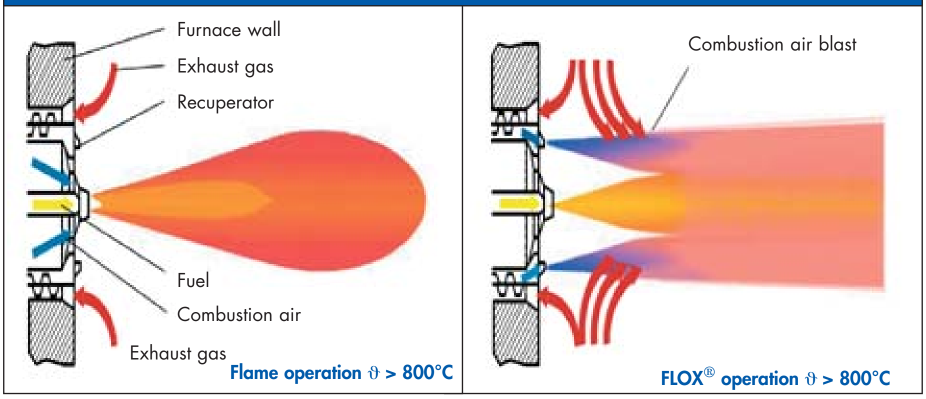
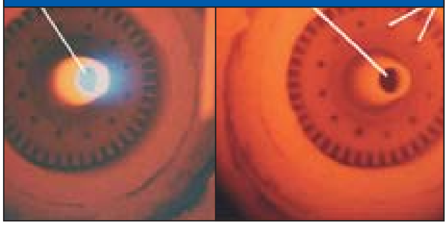


Fig. 3: Burner in flame operation (left) and in FLOX® operation (right)



With FLOX® burners, combustion gas and combustion air flow into the combustion chamber at a high flow rate and unmixed (fig. 2b). The main difference to conventional burners is the very intensive internal recirculation of the exhaust gases in the combustion chamber, and the mixing of these gases with the combustion air. This, and the delayed mixing of air and combustion gas, prevents a flame front from forming. With sufficiently high temperatures of at least around 800°C, the fuel oxidises throughout the entire volume of the combustion chamber. This causes very homogenous temperatures. The formation of thermal nitrogen oxide, which primarily takes place at the flame edge with its high peak temperatures, is prevented. With the more uniform distribution of temperature, not only do the nitrogen oxide emissions decrease, but it is also possible to maintain a higher average combustion chamber temperature.

With conventional burners, the combustion processes are usually monitored with UV instruments. In flameless operation, this is not possible. Instead, the temperature of the usable space is measured. If the threshold temperature is exceeded, ignition and complete combustion are ensured.

► A beginning in the industry

The early 1990s saw the development of recuperative FLOX® burners, with which the hot exhaust gases preheat the combustion air in the burner via a heat exchanger, and of regenerative burners, with which the waste heat is used via intermediate storage. Now, the user can choose from a broad range of mass-produced products for various applications.

Steel industry

The steel industry is a pioneer in the implementation of FLOX® burners. Most burners are implemented here, in the metal industry, and in heat treatment furnaces. A decisive breakthrough came with the development of ceramic recuperative burners, which are considerably more temperature-resistant than burners made of chrome-nickel steels, and which have a long service live. With these burners, high temperature processes which previously required electricity can also be fuelled economically with natural gas. The ceramic burners not only have advantages at high temperatures, but also when it comes to using as much waste heat as possible at lower temperatures. To date, several thousand ceramic burners have been installed.

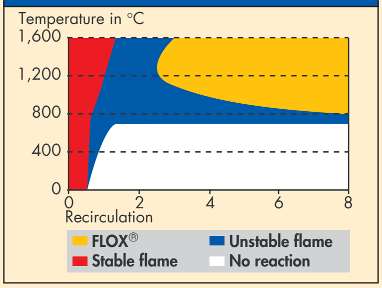
Glass and ceramics industry

In glass production and processing, significant nitrogen oxide emissions arise, which entail high costs for secondary exhaust gas purification. Therefore, there is considerable interest in low-emission production processes. Yet at the same time, there are reservations with regard to deviation from proven production methods. Many production details are based on empirical experience, which upon alterations must be reacquired, entailing considerable effort. Similar hurdles must be crossed in the ceramics industry. Here too, there is considerable potential for implementation, but simultaneously there are reservations when it comes to altering highly integrated processes. In both cases, a great deal of effort must be invested in research and persuasion in order to depart from the beaten track.

Fig. 5: Hundreds of ceramic FLOX® burners fire an annealing furnace

Fire without flame

Fig. 4: The decisive parameters: temperature and exhaust gas recirculation



In 1989, experiments with a recuperative burner lead to a surprising discovery: at furnace temperatures of 1,000 °C, and with air preheating of 650 °C, the monitoring device for the burner flame ceased to indicate a signal, and no flame could be heard. Nevertheless, the fuel burnt completely. The carbon monoxide content of the exhaust gas was below 1ppm, and the NO_x emissions were so low, that it was initially assumed that the measuring device was malfunctioning. However, the combustion was stable and uniform, without a flame having formed. The phenomenon was named "flameless oxidation", or FLOX® for short. In further experiments in the research project sponsored by BMWi, the researchers were able to determine the conditions under which flameless combustion is possible (fig. 4). It soon became evident that the process enabled considerable energy savings. Low emission values were also achieved when using exhaust gas heat for intensive combustion air preheating. Thus, BMWi approved a multitude of follow-on projects. The discovery ultimately led to a combustion process, patented worldwide, with numerous possibilities for implementation.

▶ And new fields of application...

Lean gases can be utilised

Various research projects are examining how landfill gas, coalmine gas, biogas, sewage gas, product gas, or wood gas, can be used in an energy-efficient manner with low emissions. This work often involves lean gases with a low energy content compared to natural gas. Furthermore, in many cases the fuel quality often fluctuates in the short term, e.g. with gases from production processes, or over a longer term, e.g. with landfill gases. Today, lean gases are often still burnt off, so that climate-damaging methane does not escape into the environment.

FLOX® burners deal with low-energy gases better than conventional burners do, and with flameless oxidation, fluctuating fuel quality does not immediately cause problems with flame stability.

In the European research project BIO-PRO, burners are being developed for biorefineries. These are systems which convert biomass into fuels, chemicals, and even foodstuffs. In these processes, solid, liquid, and gaseous residues arise. To enable combustion of solid fuels as well, researchers at the University of Stuttgart are investigating the use of FLOX® burners with various pregasifiers.

For clean combustion of lean gases, the conversion of the nitrogen compounds contained in many lean gases must be kept within tight limits. In the laboratory, it has been shown that this is possible. Now it needs to be confirmed on an industrial scale. To this end, alongside constructive approaches, the development of a new type of burner controller is being promoted. If this project succeeds in producing the required confirmation, this technology can be offered on a commercial basis in the future.

Together with the University of Bochum, the Gaswärmeinstitut (Gas-Fired Thermal Energy Institute) in Essen, Germany, is developing new burners and combustion chamber concepts for micro gas turbines. Here, it is possible to use lean gases which only have a third of the heating value of natural gas. In so doing, the levels of nitrogen oxide and carbon monoxide fall well short of the TA Luft threshold values for the combustion of landfill gas, biogas, and wood gas in gas turbines.

Mini combined heat and power plant

For decentralised combined heat and power generation, SOLO Kleinmotoren GmbH has developed a marketable Stirling motor. This engine, with an electrical capacity of 9kW, is suitable for hotels, swimming pools, schools, hospitals, residential buildings, or businesses. It can be operated using different heat sources. For natural gas operation, a FLOX® burner with air preheating is provided.

Fig. 6: Mini CHP plant with Stirling motor

On-site hydrogen production

To date, hydrogen is mainly produced industrially. Consumers satisfy their requirements by means of pressure cylinders or hydrogen pipelines. Now, natural gas can be used to cover these requirements on site. This is made possible by modular reformers, which are approximately as efficient as large-system reformers are. The reformers are based on conventional steam reforming from natural gas. The temperatures of around 800 °C which this requires are provided by FLOX® burners. Due to a new type of heat management, the reformers achieve energy conversion efficiencies of over 80%. In the future, this technology could enable broad implementation of PEM fuel cells.

Two product series have been developed to date. One version for industrial implementation is already marketable, with hourly capacities of 50 to 400 Nm³. The reformer has a modular structure. The capacity can be adapted to the application in an economical manner via the number of reformer tubes. Several reformers have already been commissioned and, for example, are supplying a hydrogen filling station at Munich Airport.

A second series, which is compact, should enable the use of fuel cell stacks for domestic power supply. Here too, the prototypes are already achieving conversion efficiency of over 80%. Before a market launch, work is still being done towards maximisation of efficiency, operational safety, and optimisation of gas purification.

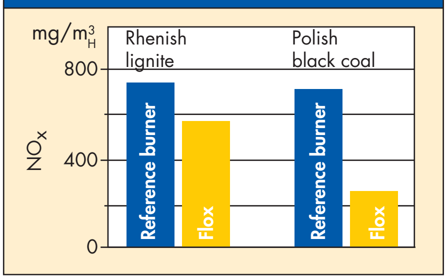
Fig. 7: Fuel cell system with FLOX® reformer for domestic energy supply

▶ Clean coal-fired power plants with coal dust combustion

In the European research project FLOX®-COAL, the University of Stuttgart is developing a pilot system for flameless combustion of pulverised coal.

Experiments at the University of Aachen show that this technology can also be developed for pressurised pulverised coal firing in coal-fired power plants. Here, the coal dust burns at pressures of up to 20 bar, and at temperatures of up to 1,450 °C. Measurements from a test system show considerable reduction of NOx concentrations in comparison to a conventional reference burner. For Rhenish lignite, the NO_x values drop by around 20%, and for Polish black coal by around 65%. Pressurised pulverised coal firing is a key technology for the development of highly efficient gas and steam power plants, also for operation with black coal. This could allow the efficiency of a black-coal-fired power plant to be increased from today's level of around 45%, to much more than 50%.

Fig. 8: Reduction of nitrogen oxide emissions with FLOX® burners



▶ Future prospects

In industry, FLOX® burners are primarily used because they entail low nitrogen oxide emissions, even with intensive preheating of combustion air. Thus, exhaust gas heat can be utilised, even with high process temperatures, which reduces the fuel requirement by up to 50%. This technology offers further advantages: the combustion chamber has a more uniform temperature distribution, the burner's thermal load and noise emissions are lower, the burners are often more reliable, and they have lower quality requirements of the combustion gas. Climbing energy prices and strict emissions requirements will serve to promote the implementation of FLOX® burners further. New developments, for instance in combustion processes for glass-melting tanks, broaden the fields of application for this technology.
Globally, interest in flameless combustion is growing outside the traditional fields of application. In research, there is a particular focus on electricity generation, using conventional energy sources and also using energy sources which have as yet not seen much use, e.g. lean gases.
With a clean and reliable technology, lean gases can be used for generation of heat and electricity much more often than they have been to date. If used consistently, it is possible to increase the utilisation of biomass in Europe by 50%. At the same time, the nitrogen oxide emissions from biomass combustion could be decreased by 76,000 tonnes per year.
Flameless combustion can assume an important role in power plant technology. WS-Wärmeprozesstechnik GmbH is researching the implementation of FLOX® in gas turbines in cooperation with DLR, the Deutsche Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Centre).
By far the greatest potential for CO_2 reduction is in efficient coal combustion. In the international research project FLOX®-COAL, a pilot system has been realised for the combustion of pulverised coal. Here, with the flameless burner, extremely low NO_x emissions are achieved. Also of significance is that flameless combustion can be an important component of a CO_2-free fossil power plant. In the new joint project OXY-COAL-AC, researchers from various tertiary institutions and companies are now working on the implementation of this idea. The individual projects are sponsored by the German Federal Ministry of Economics and Technology (BMWi), the North Rhine-Westphalia Ministry of Science and Research (MWF), and industrial partners. Initial projects were approved as part of COORETEC, the "research and development concept for low-emission fossil-fuelled power plants" initiated by BMWi at the end of 2003.

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▶ ADDITIONAL INFORMATION

Literature

- Wünning, J.A.; Wünning J.G.: Brenner für die flammlose Oxidation mit geringer NO-Bildung auch bei höchster Luftvorwärmung. In: GasWärme International. Jg. 41 (1992), H. 10, S. 438-444
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Images

- Figs. 1, 3, 5, 7: WS Wärmeprozesstechnik GmbH
- Figs. 2, 4: Nach Erdgas.report 1/03 VNG – Verbundnetz Gas Aktiengesellschaft
- Fig. 6: SOLO Kleinmotoren GmbH
- Fig. 7: Zentrum für Sonnenenergie- und Wasserstoff-Forschung (ZSW)

Service

- Additional information such as literature and internet links are available online from BINE at www.bine.info (Service/InfoPlus) in German.

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■ **Project Funding**
Federal Ministry of Economics
and Technology (BMWi)
D-11019 Berlin

Project Management Organisation Jülich (PTJ)
Research Centre Jülich
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D-52425 Jülich

■ **Project Number**
0328857A,B,C,D,E
0326939A,B,C
0326940A,B,C,D
0327274A
0327341A,B,C

IMPRINT

■ **ISSN**
0937 – 8367

■ **Publisher**
FIZ Karlsruhe
D-76344 Eggenstein-Leopoldshafen

■ **Editor**
Dr. Franz Meyer

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