Lechner P. (Hrsg.): Waste matters. Integrating views. 2nd BOKU Waste Conference 2007, 16. - 19. April 2007, Wien. Proceedings; Facultas Verlags- und Buchhandels AG, ISBN 978-3-7089-0060-5

Development of Progressive Combustion Systems for Low Calorific Landfill Gas

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Abstract
An energetic use of alternative fuels such as landfill gas makes good sense due to the continuous increase of energy prices. Besides, landfills are geographically scattered, thus it is profitable to use their gases for decentralised heat and electricity production. However, the heating value of gas recoverd from landfills is continually decreasing (because the fraction of CH_4 becomes lower as a function of time). Due to this reduction in the quality of the gas and the fact that a gas with a low calorific value is generated (heating value lower than 3 kWh/m^3_N), such gases cannot be utilised efficiently by normal combustion units. Additionally, these combustion concepts frequently do not deliver any sufficient flame stability at the burning of low caloric fuels. High emissions of harmful substances such as CO and NO_x are another problem. Thus it is necessary and also a challenge to develop progressive and flexible combustion systems which can handle these problems. In this contribution activities of Gaswärme-Institut e. V. Essen (GWI) regarding burner development, modification work, tests made and results achieved will be presented and explained.

1 Introduction
In close collaboration with research and industry partners Gaswärme-Institut e. V. Essen (GWI) developed in the frame of national and European projects two burner systems which are able to efficiently utilise different gas qualities generated by landfills. The technology developed is based on the innovati ve burning concepts of continuous air staging (COSTAIR) and flameless oxidation (FLOX[1®]). In this context GWI carried out an extensive program of simultaneous numerical and experimental investigations using different gas mixtures composed from components of landfill gas like CH_4, CO_2 and N_2. The heating value varied between 1 and 3 kWh/m^3_N. Through the comparison of numerical simulation results for different burner geometries optimal burner designs were proposed and experimentally tested. The calculation data gained confirmed the experimental

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trends for the combustion behaviour and proved the usefulness of applied modelling approaches.

Depending on the industrial application required, experiments were carried out with preheated or unpreheated combustion air and with different gas mixtures, respectively. Results achieved proved a high potential of the combustion systems developed for the use of different qualities of low calorific landfill gases. The combustion process was at any time stable and almost pulsation free. Emission values for NO_x and CO lower than 10 ppm could be achieved for a wide range of air ratios at high volumetric heat density.

2 Combustion concepts

The COSTAIR combustion concept uses the principle of continued staged air to suppress formation of NO_x. Figure 1 illustrates schematically its design. It consists of a coaxial tube; the combustion air flows through the inner tube and the

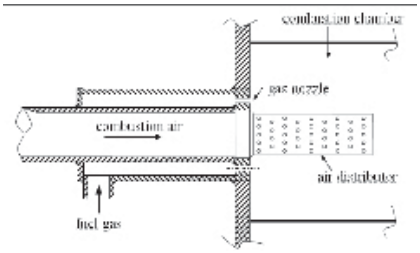


Fig. 1: COSTAIR combustion concept

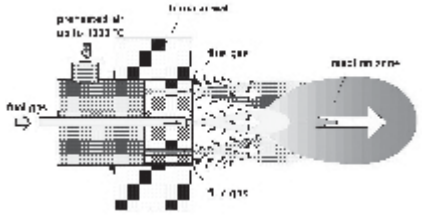


Fig. 2: FLOX combustion concept

fuel through the outer cylinder ring. The combustion air is continually distributed into the combustion chamber by means of an air distributor with numerous openings on its contour. The fuel enters the combustion chamber by means of several nozzles arranged around the air distributor. The COSTAIR burner has the advantages of operating in full diffusion mode or in partially premixed mode.

The flameless combustion concept FLOX, presented in Figure 2, is based on high internal flue gas recirculation rate, which is realised by the high momentum of the preheated air nozzles entering the combustion chamber. Thus, diluted combustion takes place. Under specified conditions, a controlled flameless oxidation without pulsation and with almost complete burnout can be achieved. Due to the high ratio of recirculated flue gas, the maximum reaction temperature in FLOX operation mode is below 1500°C, while the formation of NO_x is reduced considerably.

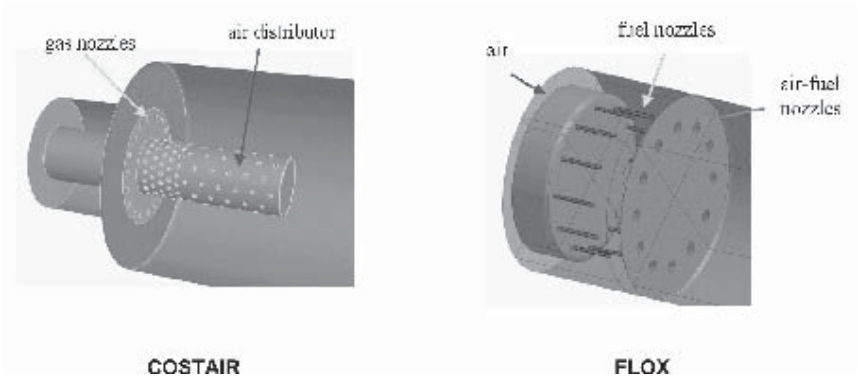
3 Development methodology

To achieve the most useful shape and dimension of burner configurations for utilising low calorific landfill gases efficiently, several development steps were

made. First, extensive numerical calculations using the CFD code FLUENT were carried out for a small burner load at 20 - 30 kW. Based on results achieved, the more efficient burner variant has been determined in the second step. Among others, the determination criteria were the combustion and pollution behaviour of the burner (such as flow and temperature distributions, recirculation and reaction zone size, NO_x and CO emission levels). In the next step the selected burner variant was built and tested experimentally. During these tests, simultaneous modification work was done to some burner parts to improve the combustion performance. Finally, experimental results achieved for all variants were compared among each other, thus the burner configurations for efficient industrial use could be set up.

4 Numerical simulation results

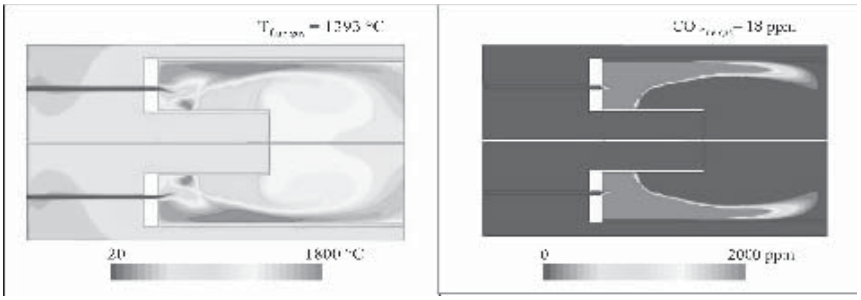
In the frame of the EC project "New Combustion Systems for Gas Turbines" detailed CFD simulations have been made by Flamme et al. (2004) on the COSTAIR and FLOX combustion concepts to optimise them for efficient use of natural gas in gas turbine combustors. The most convenient burner configurations are illustrated in Figure 3. These configurations served as a basis for further numerical modifications for the use of bio and lean gas in different industrial applications. The calculation parameters were adjusted to the real industrial conditions. The



full description of mathematical models used, calculation conditions and results achieved are published by Al-Halbouni et al. (2006), Rahms and Al-Halbouni (2006) and Al-Halboui, Rahms and Giese (2006). Here only an extract from results of calculations made for two industrial processes will be represented and analysed.

Fig. 3: Basicburner configurations for low calorific gases

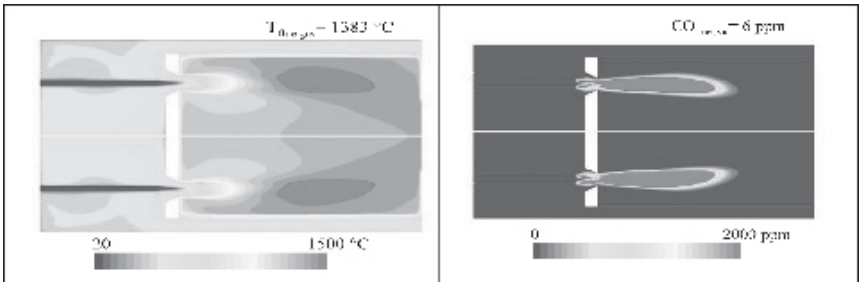
The first simulation case dealt with the use of landfill gas in micro gas turbine combustors to produce heat and power. For this application burners had to work stable at high air ratios, i. e. $\lambda = 2$ to 3, and preheated combustion air (500 - 600°C). The CFD calculations were made to optimise the burners for the turbec micro gas turbine T100. In accordance with the turbine capacity the thermal load of the burner was set to 80 kW at atmospheric pressure.
Figure 4 shows the temperature and CO distributions calculated for the best



burner configuration found for the COSTAIR burner at an air temperature of 500°C. The combustion behaviour confirms high temperature values in the region around the air distribution, near to the combustion chamber wall. In the upper part of the combustion chamber the temperature distribution is going to be more and more regular; thus, as the CO emission values proved, complete burn-out is achieved at the outlet of combustion chamber.

Fig. 4: Calculated temperature and CO distributions of the COSTAIR burner for a burner load of 80 kW/bar at an air ratio $\lambda = 2$ and an air temperature of 500 °C

Figure 5 shows the temperature and CO emission distributions for the best FLOX burner configuration found by numerical simulations. At the same calculation



conditions as for the COSTAIR burner, the FLOX burner shows high temperature values directly over the gas/air nozzles in the upper part of the combustion

chamber. The temperature distribution is going to be more even at the outlet. In the middle of the combustion chamber, where a large flue gas recirculation area predominates, the temperature profile seems to be regular. As the CO emission values confirm, this combustion behaviour leads to a good burn out.

Fig. 5: Calculated temperature and CO distributions for the FLOX burner for a burner load of 80 kW/bar at an air ratio λ = 2 and an air temperature of 500 °C

Regarding NO concentration, the numerical simulations led to values less than 1 ppm for both combustion systems furthermore, the CFD calculations confirmed the same combustion behaviour at elevated and atmospheric pressure conditions (see results published by Al-Halbouni et al., 2006).

The second simulation case dealt with the use of landfill gas in industrial boilers to generate hot water and superheated steam. This application demands lower air ratios, i. e. λ= 1.05 to 1.4 and cold combustion environmental conditions, as in a water boiler. In a frame of a national project GWI did extensive CFD simulation work to modify the COSTAIR burner for this application. Figure 6a shows the

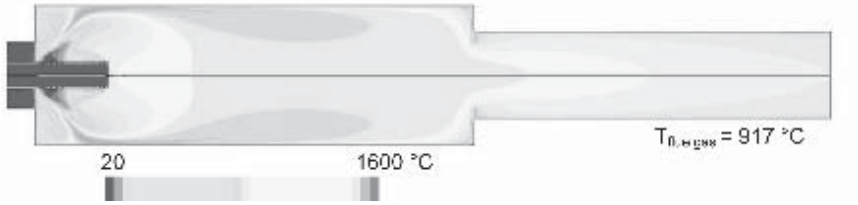


Fig. 6a: Calculated temperature distribution for the COSTAIR burner using low calorific gas mixture at 200 kW and λ = 1.3

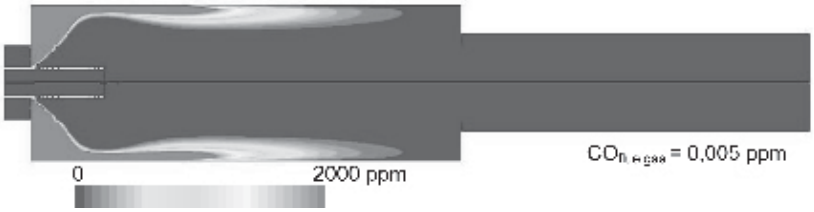


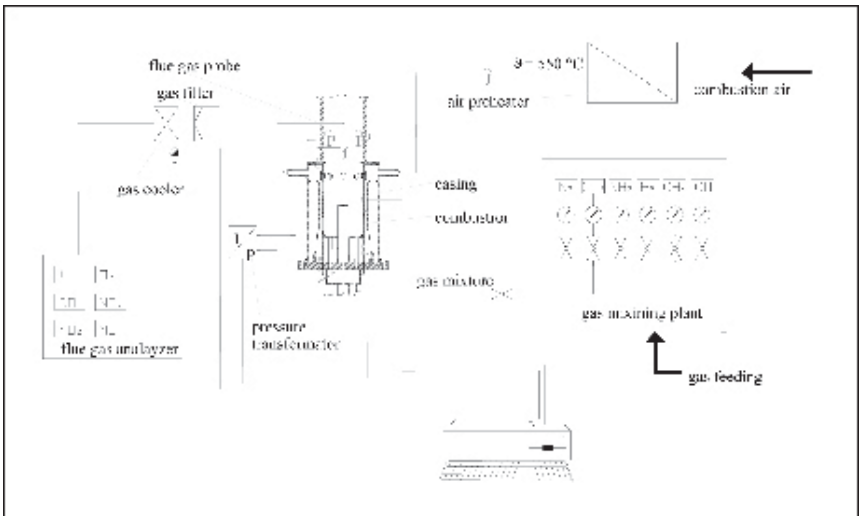
Fig. 6b: Calculated CO distribution for the COSTAIR burner using low calorific gas mixture at 200 kW and λ = 1.3

calculated temperature distribution and 6b the corresponding CO distribution for a landfill gas mixture consisting of 25 vol.-% CH_4 and 75 vol.-% N_2. The results demonstrated here were achieved at an air ratio λ = 1.3 for a thermal burner load of 200 kW. As shown in this figure, the temperature distribution is almost regular and burn out could be achieved inside the combustion chamber of the boiler. The best burner configuration found was used for experimental tests.

5 Experimental results

5.1 Results at micro gas turbine test rig

In an already finished national project extensive experiments have been carried out for the use of the new combustion systems COSTAIR and FLOX for bio and lean gas fired micro gas turbines. Results achieved have been published by Flamme et al., (2005). Currently, in a follow-up national project, experiments are being run on a very compact test rig corresponding to the combustor of turbec micro gas turbine T100. Figure 7 shows a schematic presentation of the whole



GWI test plant including test facilities. This test plant is equipped with all needed devices for measurement of concentrations, temperatures and pressures. The fuel supply system enables producing several low calorific gas mixtures by a gas mixing plant. The compositions of landfill gas CO_2, N_2 and CH_4 were mixed together in pre-assigned amounts to get a typical low calorific landfill gas quality. The combustion air was preheated before entering the combustion chamber.

Fig. 7: Schematic presentation of GWI test plant for micro gas turbine applications

The operation conditions for the experiments were as follows:

- Temperature: for gas mixture 20 °C, for combustion air 500 °C
- operating pressure: atmospheric
- thermal burner load: 80 kW (specific volumetric heat density ≈ 20 MW/ m^3bar)
- air ratio: 1,5 - 3,5 without secondary air and 3,5 - 8 with secondary air admixing

Tab. 1: Compositions of landfill gas mixtures tested experimentally

Landfill gas mixture no.	**Compositions [vol.-%]**			**heat value H_i [kWh/m^3_N]**
	CH_4	**N_2**	**CO_2**	
Mixture 1	30 - 15	70 - 85	-	≈ 3 - 1
Mixture 2	25	65	10	≈ 2,5

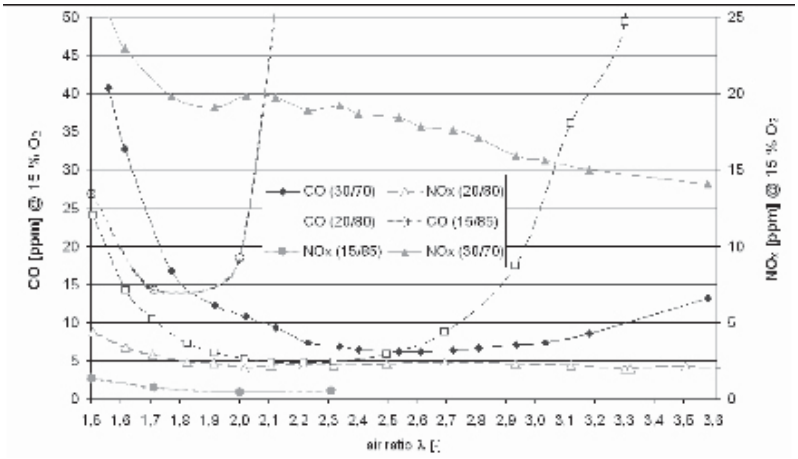


Fig. 8: Experimental results of the COSTAIR burner for gas mixture no. 1, operation without secondary air admixing

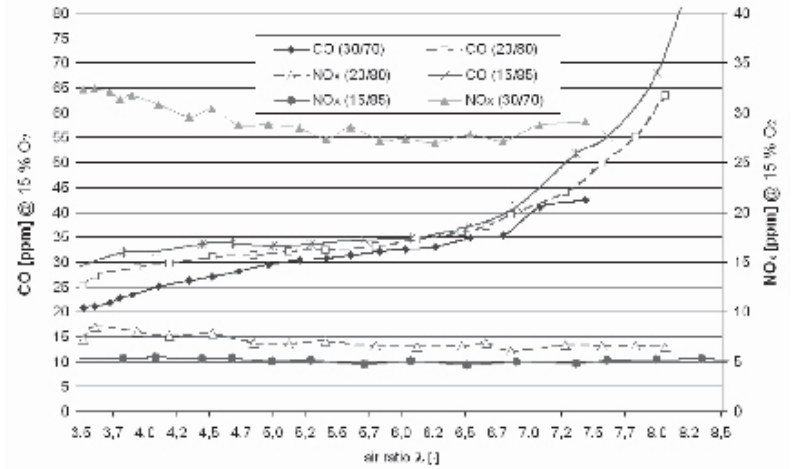


Fig. 9: Experimental results of the COSTAIR burner for gas mixture no. 1, operation with secondary air admixing

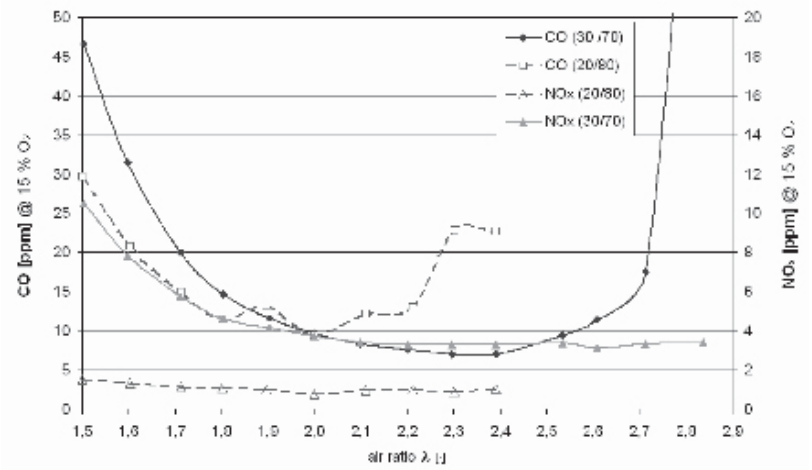


Fig. 10: Experimental results of the FLOX burner for gas mixture no. 1, operation without secondary air admixing

Two different landfill gas mixtures have been tested. The first mixture consists of CH_4 and N_2 and the second one CH_4, N_2 and CO_2. Table 1 contains the compositions of these mixtures.

Figures 8, 9 and 10 show first results achieved on the burner systems COSTAIR and FLOX. Both burners worked stable and almost pulsation free in the range of the air ratio given.

5.2 Results at industrial boiler test rig

In the frame of a still running national project, Gaswärme-Institut e. V. Essen (GWI) is preparing the combustion concept of continous air staging (COSTAIR) for the use of natural and landfill gases for industrial boiler applications. The test rig used for the experiments is shown in Figure 11. The measuring facilities are the same as those presented in Figure 7. For ignition an electrode and for combustion controlling an UV probe was installed at appropriate positions.

For the first experimental tests burner configuration found by numerical simulations has been used. To validate the numerical results and to modify the burner design tests have been done first without water-cooling. The burner configuration leading to a stable combustion and low pollutant emissions has been chosen for detailed investigations.

In addition to natural gas, a low calorific gas mixture corresponding to landfill gas has been used. The components of this mixture are CH_4 and N_2. Their proportions were selected according to values given for mixture no. 1 in Table 1. The

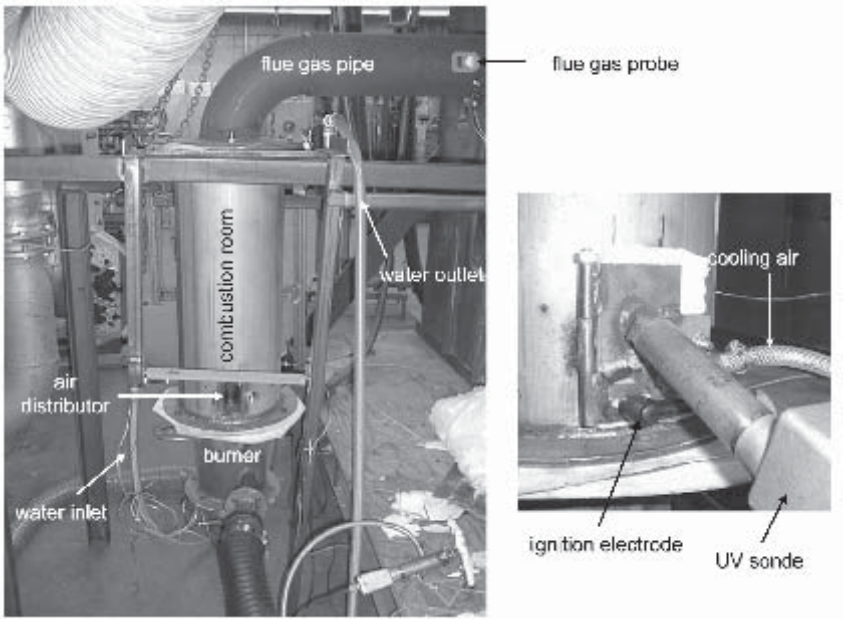


Fig. 11: GWI industrial boiler test rig

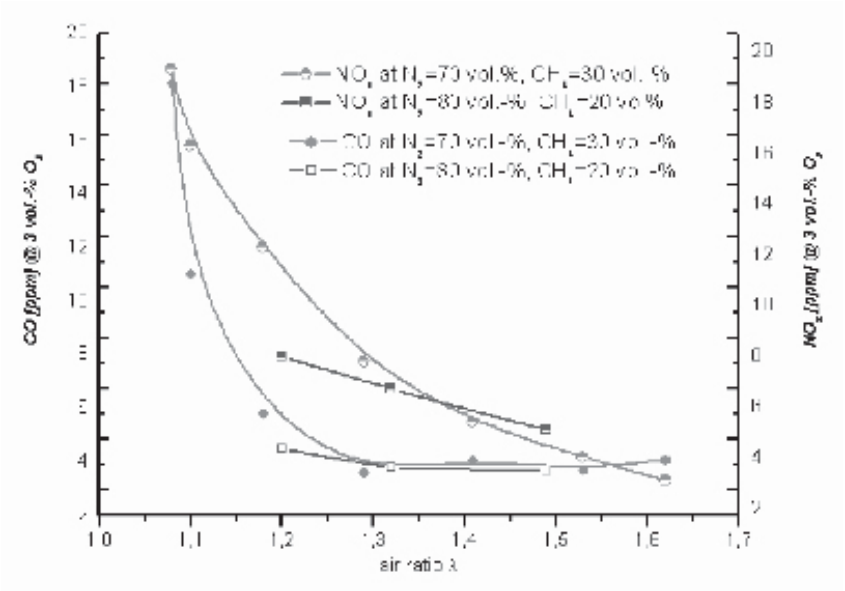


Fig. 12: Experimental results of the COSTAIR burner for gas mixture no. 1 at an industrial boiler test rig without water-cooling

thermal burner load has been set to 200 kW to demonstrate high capacity of burner performance as required for industrial boilers. Figure 12 shows the measured NO_x and CO emissions for the mixture mentioned over the air ratio of interest for industrial boiler applications. As seen, emission values lower than 10 ppm (at 3 vol.-% O_2) could be achieved. The combustion was stable at any time and almost pulsation-free. In the next step of the investigation, experiments are planned to be carried out in a water-cooled test rig to justify the burner and certify the results.

6 Conclusions and future work

The major technical conclusion from the results achieved is that the combustion systems developed work stable and efficiently for burning low calorific landfill gas with different compositions.

For micro gas turbine applications NO_x and CO emission values are generally lower than 30 ppm at 15 vol.% O_2. Even single digit values can be achieved.

For industrial boiler applications NO_x and CO emission lower than 10 ppm at 3 vol.-% O_2 are possible.

Future work will be focusing on experimental tests of prototype burners at the micro gas turbine T100 and at an industrial boiler to collect evidence for efficient burner operation under real industrial conditions.

7 Acknowledgements

Results presented here are from national projects funded by the German Ministry for Economics through the Arbeitsgemeinschaft industrieller Forschungsvereinigungen - AiF - (project no 14472 N) and partly sponsored by the German Federal Environmental Foundation - DBU - (project no AZ 22749-24/0), respectively.

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