An Efficient Combustion Concept for Low Calorific Gases

A. Al-Halbouni; H. Rahms and K. Görner

Gaswärme-Institut e. V. Essen, Hafenstr. 101, D-45356 Essen, Germany
phone: +49 201 3618239; fax: +49 201 3618238; e-mail: halbouni@gwi-essen.de, rahms@gwi-essen.de, klaus.goerner@uni-essen.de

Abstract

The main features of low calorific gases as those from biomass gasification processes, landfills, mines and sewage sludge are well known. They can be expressed as low calorific values, high water content, corrosive actions and composition changes. Due to these characteristics there are up to date no combustion systems available which are capable to utilise such gases efficiently. The ordinary combustion concepts frequently do not guarantee sufficient flame stability. The high emissions of harmful substances as CO and NO_x are another problem. Because of mentioned difficulties it is necessary and also a challenge to develop an efficient and flexible combustion system which can handle these problems.

Through several matching steps of numerical and experimental investigations Gaswärme-Institut e. V. Essen (GWI) developed a progressive combustion system based on the concept of continuous air staging (COSTAIR). Burner tests at a small scale thermal load of 30 kW proved a stable combustion and low NO_x and CO emissions for different qualities of low calorific gases. The best design of a small scale burner was transferred to larger thermal loads by applying of scale-up criteria. Already achieved experimental results at 200 kW_{th} confirmed the efficient performance and the high potential of the burner for use of low calorific gases.

Keywords: Low calorific gas, Flame stability, NO_x and CO emission, COSTAIR burner

1. Introduction

Gaswärme-Institut e. V. Essen (GWI) shared nine European research parties in carrying out an EU project named Bio-Pro [1] to develop new burner technologies for low-grade biofuels to supply clean energy for processes in biorefineries. Innovative burning techniques like the flameless oxidation (FLOX®) and the continuous air staging (COSTAIR) served as a basis for the aimed development.

The main tasks of GWI dealt with the development of a progressive combustion system based on the COSTAIR technology.

In this contribution the development work done at GWI will be explained and the experimental results achieved for the samll scale burner (30 kW thermal load) and the large scale burner (200 kW thermal load) will be presented and discussed.

2. Objectives

The main goal of this research work is to develop a combustion system, which is capable to utilise efficiently low calorific fuels with different qualities. Additionally, the upper limit for CO emission of the investigated fuels should be lower than to 30 mg/Nm³; NO_x emission shall be reduced by 50 % compared to the combustion of the fuel in available combustion systems (i.e. NO_x should be lower than 150 mg/Nm³).

3. COSTAIR combustion concept

Figure 1 shows the design of the COSTAIR combustion concept. It consists of a coaxial tube; the combustion air flows through the inner tube and the fuel through the outside cylinder ring. The combustion air is continually distributed into the combustion chamber by means of an air distributor with a plenty of openings on his contour. The fuel is being injected into the combustion chamber by means of several holes. These holes are arranged in such a way that they form one or more rows around the air distributor and serve to distribute the fuel into the combustion zone in adjustable jet direction. The combustion air as well as the fuel can be swirled and supports thereby the flame stabilization and the burn-out of the fuel.

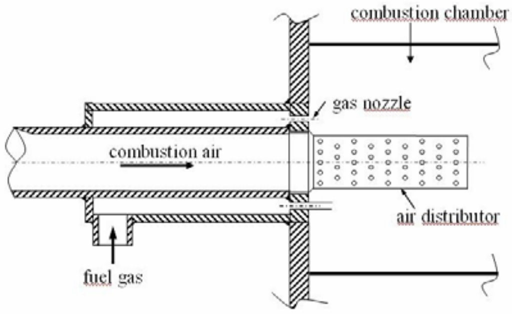

Figure 1: Design of the COSTAIR burner

® registered trade mark of WS Wärmeprozesstechnik Renningen, Germany

4. Test plant

Figure 2 shows a schematic presentation of the whole GWI test plant including test facilities. The experiments have been carried out ot a cylindrical combustion chamber, which was equipped with all needed devices for the measurement of concentrations, temperatures and pressures. The fuel supply system enabled the generation of low calorific gas mixtures. The main components of these mixtures were methane, hydrogen, nitrogen, Carbon dioxide and carbon monoxide. These components were mixed together in pre-assigned amounts by a gas-mixing plant to get a typical lean gas quality. Through two electrically driven pre-heaters the gas mixtures have been preheated up to 400 °C before entering the combustion chamber. The combustion air was led into the combustion chamber at atmospheric temperature. A probe at the outlet of the combustion chamber served to extract flue gas sample. After filtering and cooling of the flue gas sample concentrations were determined by the exhaust gas analysers. All measuring data were stored on a PC for evaluation and presentation.

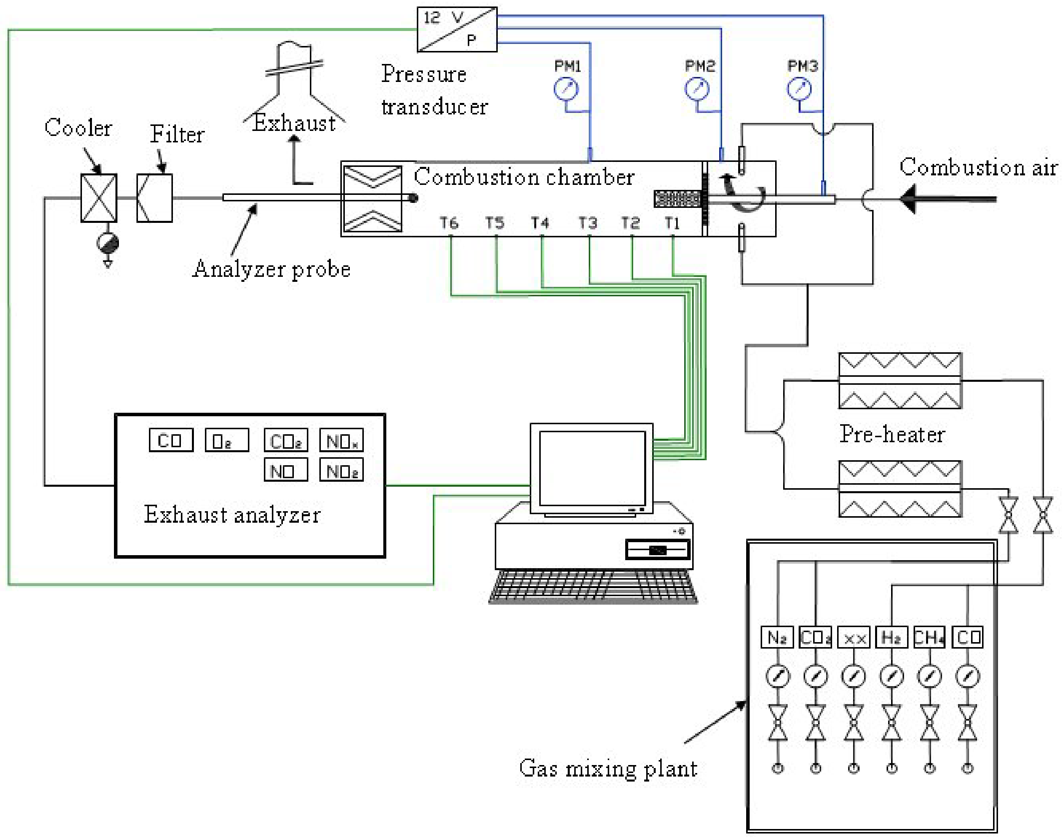

Figure 2: Schematic presentation of GWI test rig

5. Investigation methodology

Step 1: The first investigation step covered an extensive program of numerical simulation to set up an optimal small scale burner design for a thermal load of 30 kW. An overview on the operation condition, parameters and calculation models used as well as results achieved at burning of low calorific gases with different qualities is given in [2].

Step 2: Based on the numerical results gained by step 1 the small scale burner was built by GWI and tested at a thermal load of 30 kW. During the tests some additional modifications have been made to several burner parts as nozzle diameter and air distributor to optimise combustion performance.

Step 3: Through the comparison of measuring results for different variants a best burner design for 30 kW_{th} has been selected and transferred to a higher thermal load of 200 kW_{th} by use of scale-up criteria and numerical simulation.

Step 4: The burner for 200 kW_{th} has been built by GWI and validated by extensive tests with low calorific gas mixture. First achieved experimental results have been published in [3].

Step 5: The last step contained the comparison of results of the developed combustion system to current burner technologies.

6. Experimental results

All experiments were carried out under atmospheric pressure. Table 1 shows the components of the gas mixtures used for the tests as well as the corresponding calorific values. The operating conditions were: $T_{air} \approx 20°C$; $T_{fuel} \approx 400°C$; $p \approx p_{atm}$. The results achieved are shown in the figures 3 to 7.

Figures 3 and 4 represent the measured NO_x and CO emission values via the air to fuel ratio (λ) for the small scale burner. As seen from these figures NO_x emissions are for all types of gas mixtures lower than 28 ppm and CO values lie mainly between 4 and 8 ppm at 3 vol.-% O_2 in the flue gas. These NO_x and CO values are much lower than the limit values aimed at the EU project Bio-Pro [1].

The pressure for the gas mixture and the combustion air before entering the combustion chamber were at all experiments and for all gas mixtures mentioned in table 1 very low. Typical values are represented in figure 5 for the wood gas mixture.

Table 1: Gas mixtures used for experimental tests

Gas type	Composition [vol. - %]					Calorific heat value H_i [kWh/Nm^3]
	CH_4	CO	H_2	CO_2	N_2	
Biomass gasification	5	20	15	10	50	approx. 1.5
	0	21	14	10	55	approx. 1.15
Mine gas	25	0	0	10	65	approx. 2.5
Landfill gas	20	0	0	0	80	approx. 2
Wood gas	5	15	15	15	50	approx. 1

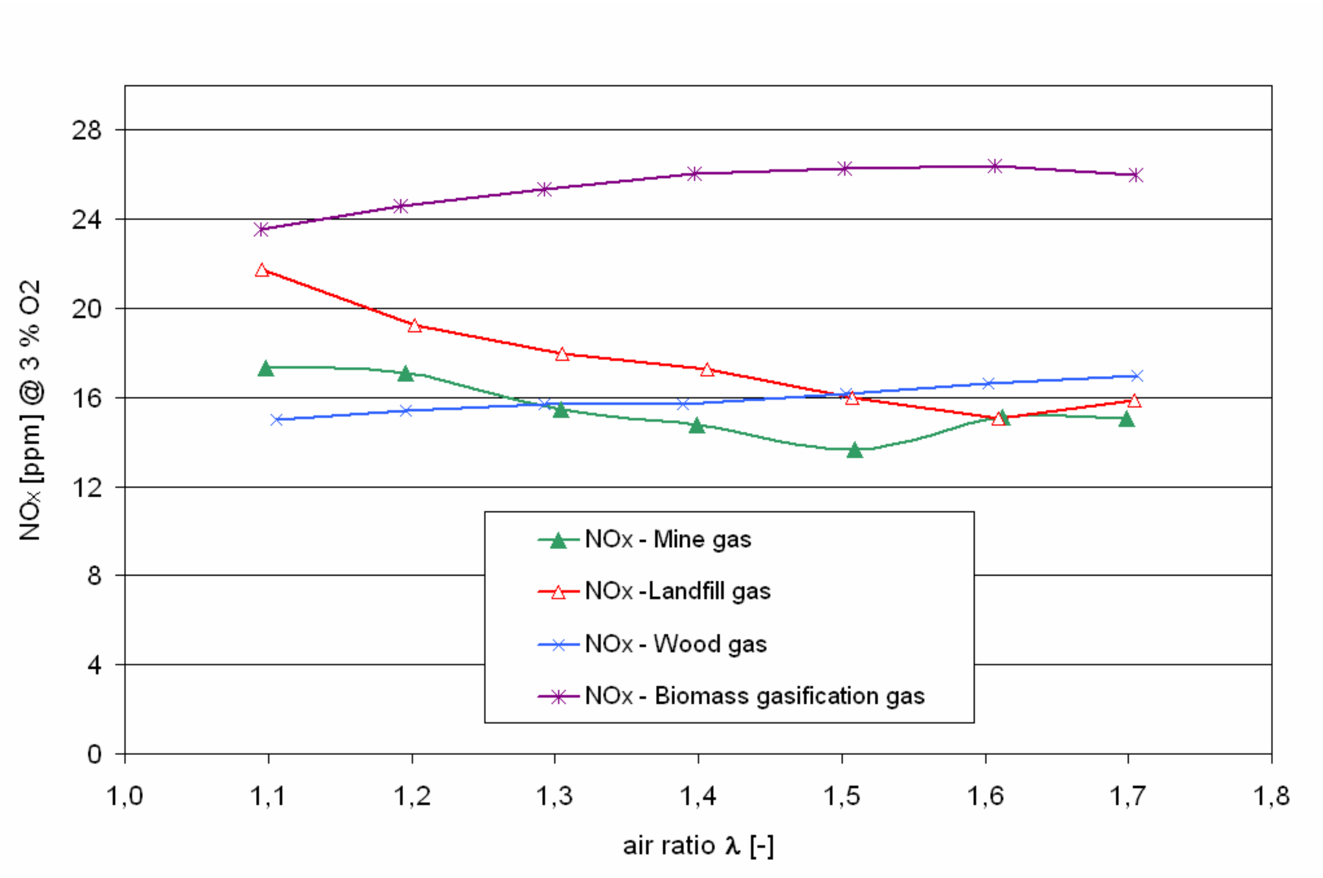

Figure 3: Measured NO_x emission values at 30 kW_{th} for different low calorific gas mixtures

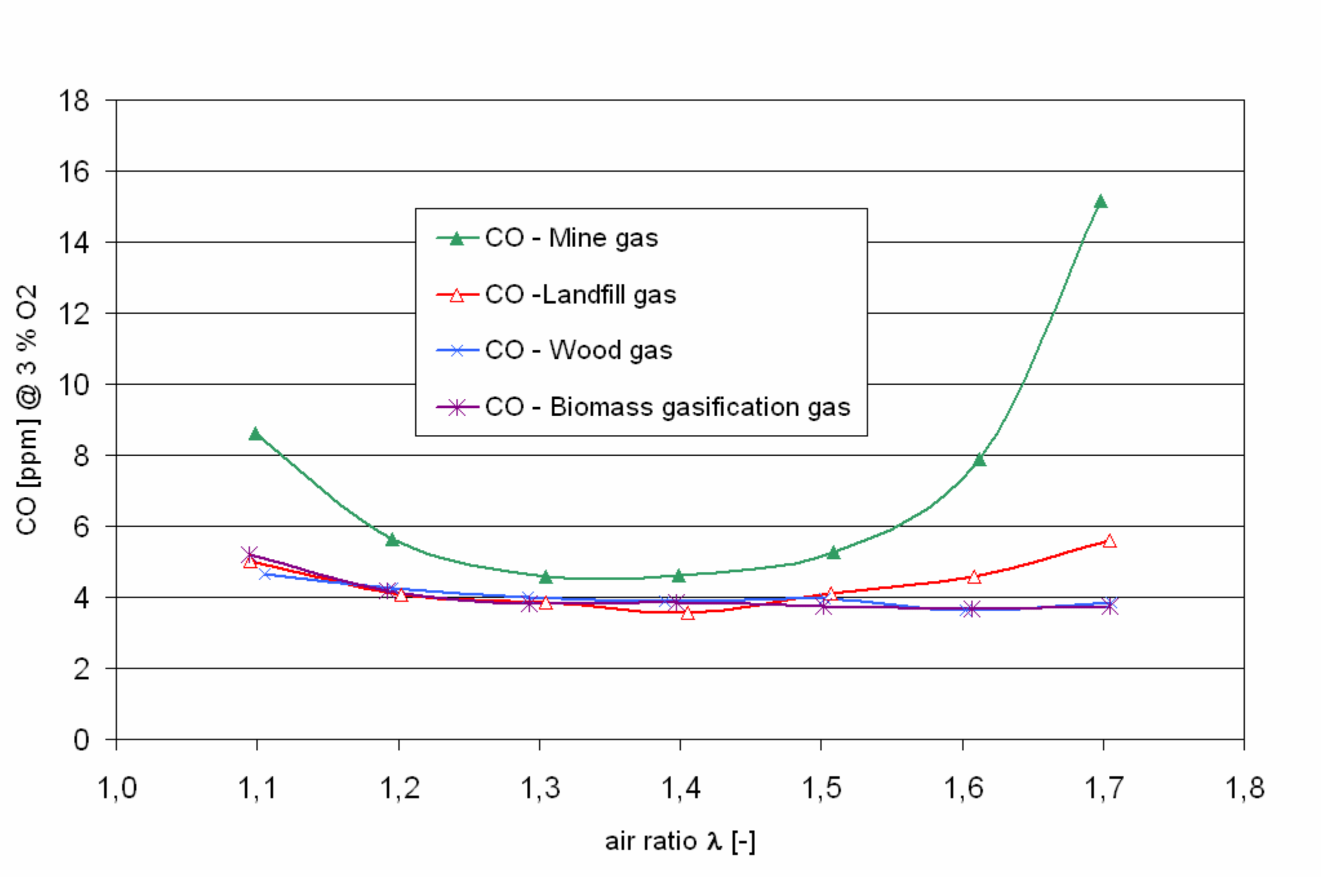

Figure 4: Measured CO emission values at 30 kW_{th} for different low calorific gas mixtures

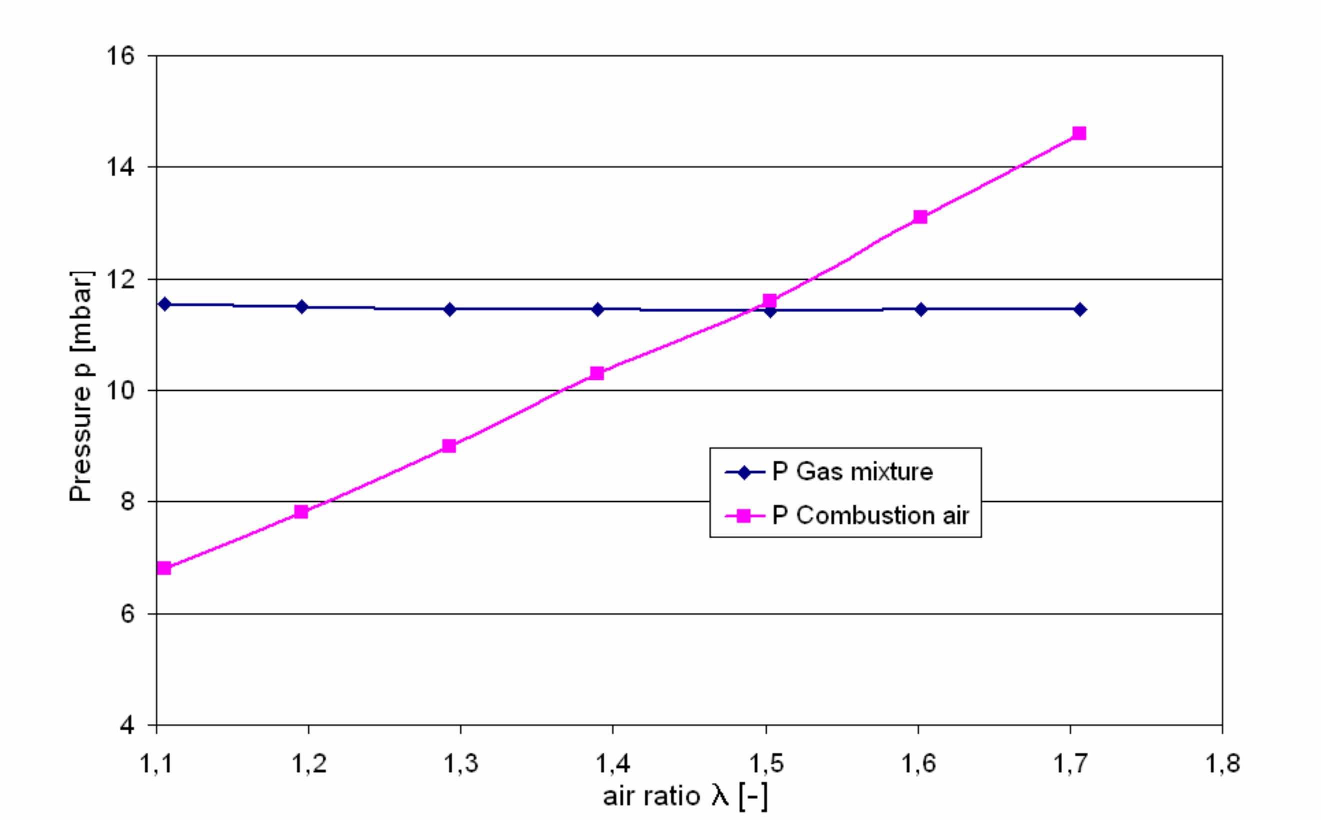

Figure 5: Measured pressures at 30 kW_{th} for wood gas mixture and combustion air

Independently from the gas mixture quality a stable and almost non-pulsating burning process could be ensured. The flame was compact and the combustion took place in the region around the air distributor as shown by the flame photographs in figure 6. The flame colour distinguished from one fuel to another, thus it is a good indicator for the heat release in the combustion chamber.

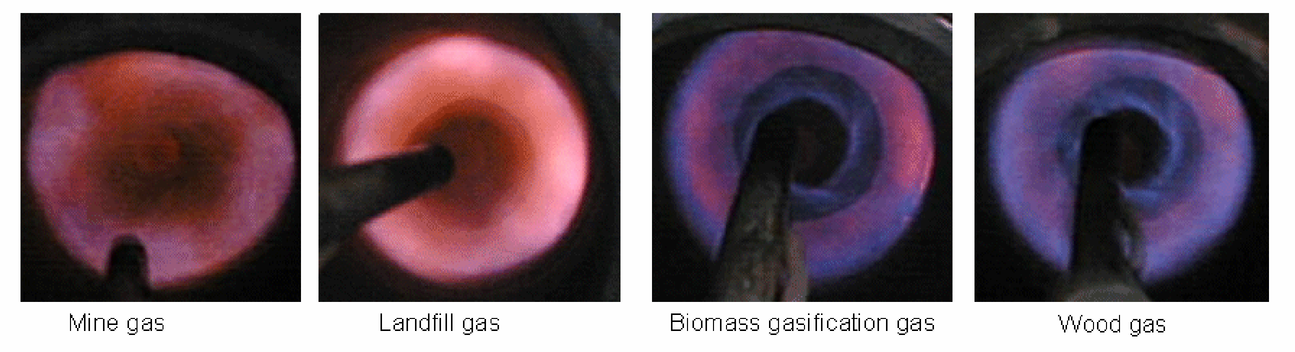

Figure 6: Flame photographs of COSTAIR burner for different low calorific gases at 30 kW_{th}

The position of reaction and heat level is reflected well in the temperature distribution on the wall of combustion chamber. As an example figures 7 and 8 show the wall temperature of the combustion chamber at different positions from the gas nozzles for tow low calorific gas mixtures. While the values of wall temperature for the gas mixture yield by biomass gasification (see figure 7) are relatively high around the air distributor and gradually decrease along the combustion chamber, the corresponding temperature values for the landfill gas mixture (see figure 8) are much lower around the air distributor and significantly higher further downstream. This behavior pointed to a compact and short flame at combustion of biomass gasification gas and longer flame at combustion of landfill gas. The reason for this is the essential influence of hydrogen fraction in both fuel types. While the gas mixture from biomass gasification contains about 15 vol.-% hydrogen, there is no hydrogen in the landfill gas mixture, as given in table 1.

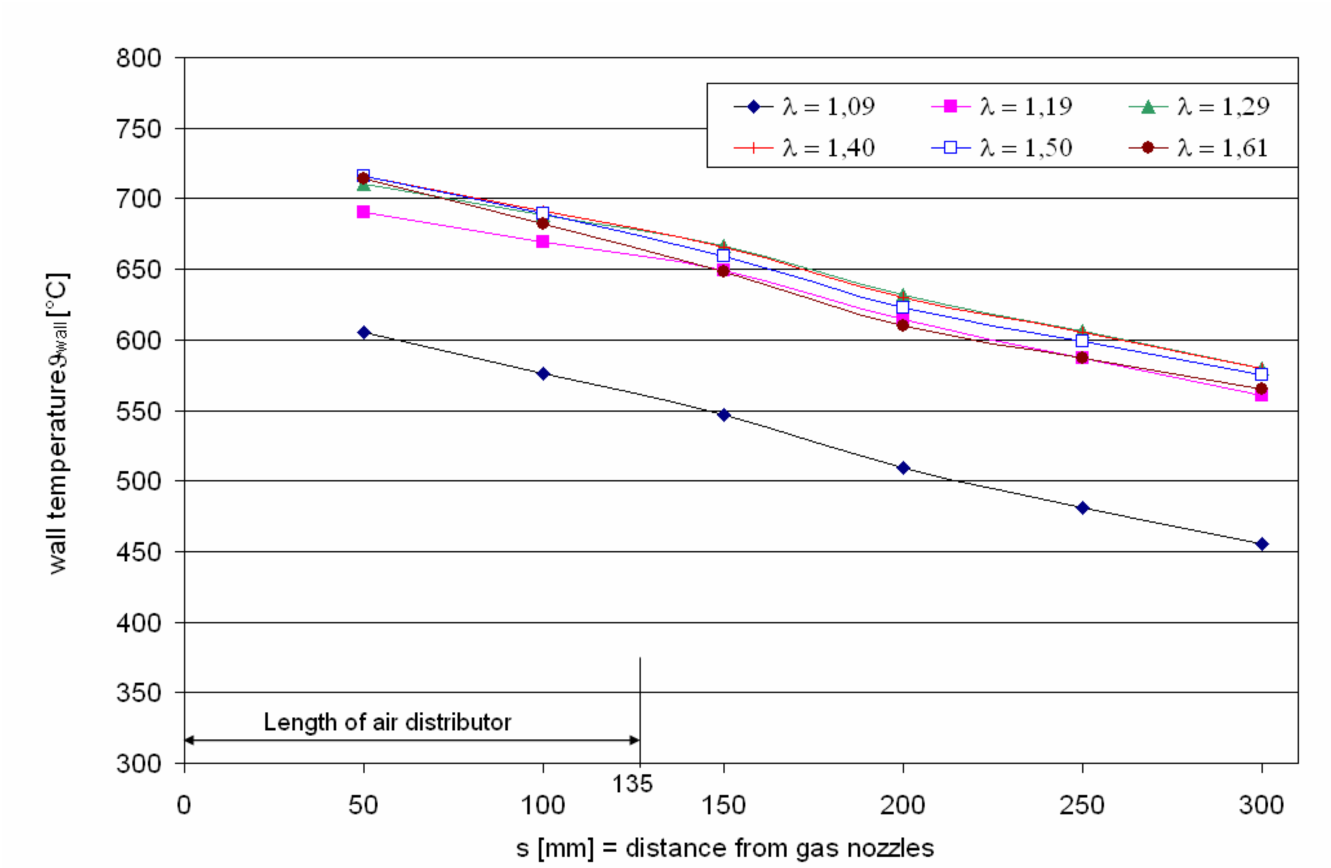

Figure 7: Temperature of combustion chamber wall for the gas mixture from biomass gasification at 30 kW_{th}

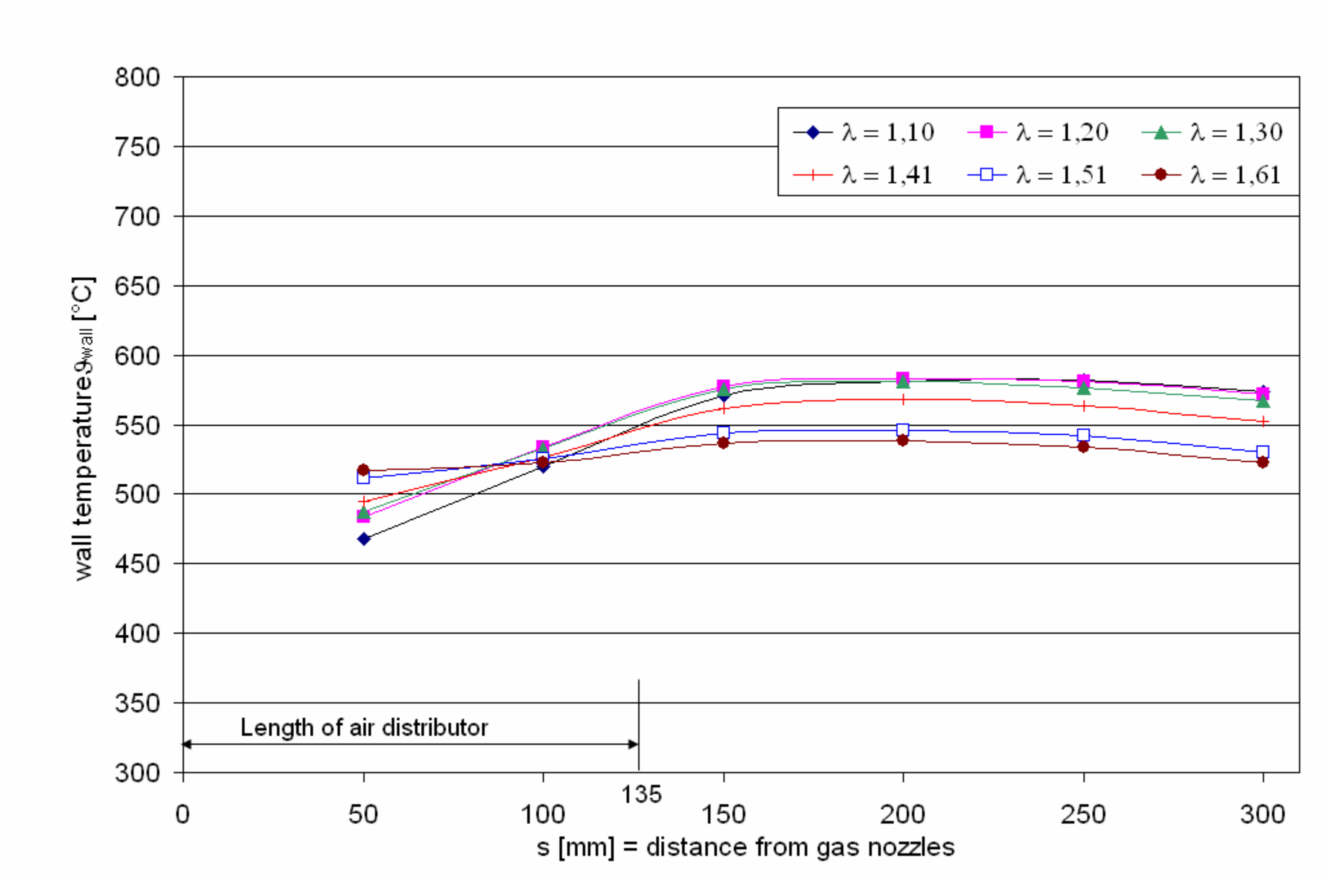

Figure 8: Temperature of combustion chamber wall for the landfill gas mixture at 30 kW_{th}

The validation tests for the large scale burner at 200 kW_{th} have been carried out at the same operating conditions as for the small scale burner at 30 KW_{th}. The fuel used referred to the second biomass gasification mixture mentioned in table 1. The calorific value of this mixture is about 1.15 kWh/Nm^3. The burner operation at 200 kW_{th} confirmed the same combustion behavior as for 30 kW_{th}. The measured NO_x emission values were below the 10 ppm–mark at each tested air ratio. At an air to fuel ratio higher than 1.3 the CO emission values fell to about 10 ppm. Beside this, a stable and compact flame could be recognized. These typically experimental results proved the usefulness of scale-up criteria to transfer burner design from small to high thermal loads. Additionally, results are an evidence for the efficiency of the developed combustion concept at burning low calorific gases.

7. Conclusions

The results achieved proved the high potential of the burner developed for the use of several low calorific gas qualities. The combustion process is stable and almost pulsation free at any time. NO_x and CO emission values lower than 20 ppm (@ 3 vol.-% O_2) can be achieved for a wide range of air ratios.

Acknowledgement

The paper presented is partly funded by the European Commission in the framework of the 6th framework programme, Priority name: Sustainable energy systems. Project: New Burner Technologies for Low Grade Biofuels to Supply Clean Energy for Processes in Biorefineries “Bio-Pro”, Contract No. SES6-CT-2003-502812.
Furthermore, the GWI research work is subsidised from funds of DVGW (Deutsche Vereinigung des Gas- und Wasserfach e. V.) und E.ON Ruhrgas AG.

References

[1] EC project Bio-Pro: New Burner Technologies for Low Grade Biofuels to Supply Clean Energy for Processes in Biorefineries. Project no.: SES6-CT-2003-502812, http://www.eu-projects.de/

[2] Al-Halbouni, A.; Giese, A.; Flamme, M.; Görner, K.: Applied Modelling for Bio- and Lean Gas Fired Micro Gas Turbines. Progress in Computational Fluid Dynamics, Vol. 6, Nos. 4/5, p 235 - 240, 2006

[3] Al-Halbouni, A.; Rahms, H.; Giese, R.: Development of a progressive combustion concept for low calorific gases from biomass gasification processes. Proceedings of the 7th European Conference on Industrial Furnaces and Boilers, Porto, Portugal, 18-21 April 2006