

Numerical investigation of laminar one-dimensional counter-flow flames from product gas of woody biomass pyrolysis and gasification

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Long Abstract

Introduction

Biomass thermochemical conversion processes are a promising alternative for decentralized biomass energetic utilization and waste treatment. In particular, processes such as pyrolysis and gasification offer the possibility of producing a fuel gas to be used, among other applications, in internal combustion engines for heat and power generation (CHP). However these fuels present higher complexity than conventional gas fuels regarding their composition depending on the conversion process. For this reason, a detailed characterization of their behaviour during combustion is needed in order to improve the engine performance as well as control and reduce emissions. Here, the behaviour of several product gases is numerically investigated in a counter-flow non-premixed laminar flame. The influence of the product gas composition on the flame behaviour and its structure is addressed and compared with the behaviour of a CH₄ flame.

1. Methods

12 different biomass-derived product gas mixtures are used in the simulations with air as oxidizer: gasification gas (GG), pyrolysis gas (PG), landfill gas (LG) and syngas (SG). These product gases are representative for several biomass sources (wood, charcoal, organic wastes) and conversion processes, i.e., pyrolysis, gasification, and fermentation (see Tab. 1). The combustion behaviour of these fuels is studied in a counter-flow non-premixed laminar flame of the Tsuji type [1] which is a crucial element for the so-called flamelet approach to modelling turbulent combustion processes.

Exp.	Biomass	CO (%)	H ₂ (%)	CH ₄ (%)	CO ₂ (%)	N ₂ (%)	LHV (MJ/Nm ³)
GG-H	Cellulose	35.5	28.7	6.5	27	2.3	9.9
GG-L1	Pine wood	27.9	35.4	4.4	30.11	2.2	8.9
PG	Pine wood	24.5	4.8	1.6	7.9	61	4.2
GG-L2	Pine wood	37.7	27.2	4.8	28.9	1.5	9.4
GG-W	Wood	20	18	2	12	48	5.2
PG-Lu	Pine bark	26	1.6	8.3	61.5	2.6	6.4
GG-S	Biomass waste	24	21	0	0	55	5.3
GG-C	Charcoal	30	7	1	2	60	4.9
GG-V	Crude glycerol	19.7	59.1	11.5	6	3.7	12.9
LG-B	Organic wastes	0	0	50	50	0	17.9
LG-R1	Organic wastes	0	0	41	53	6	14.7
GG-L3	Pine wood	24.5	4.8	1.6	7.9	61.0	4.2

Figure 1. Product gas composition and LHV for the gas fuels under investigation

To simulate the flame, a Fortran code developed by Behrendt [2] has been used. This code solves the governing (conservation) equations for mass, momentum, energy and mass fraction for non-stationary laminar one-dimensional flames. Therefore, it can be used to investigate the impact of different operating conditions or fuel composition upon laminar combustion behaviour.

2. Results

Increasing the flow velocities results finally in aerodynamic quenching of the flame. This extinction

shown in Fig. 2 a). The higher the critical strain rate, the higher the resilience to quenching, making the flame more stable for a wider range of flow conditions. That is desirable for an industrial combustion system, since the turndown ratio of the burner could be therefore increased, allowing a wider range of firing rates and thus enhancing the flexibility of the system. In Fig. 2 b) the critical strain rate for flame extinction is plotted against the molar fraction of hydrogen in fuel gas. When compared with methane combustion, it can be said that biomass derived gases with a hydrogen molar fraction higher than 5-10 % present a similar resilience to quenching as CH₄. Fig. 2 c) and d) show the NO profile for the strain rate 10 1/s and close to extinction for each gas. NO is one of the most important pollutants in combustion. Of course, higher flame temperatures lead to higher NO emissions, which is the case for low strain rates (10 1/s). For the situation close to extinction the only significant NO emission is in the case of pure CH₄ or fuels with high CH₄ content. It is observed that basically the dominating NO formation mechanism is the thermal mechanism hence lower temperatures lead to reduction in NO emissions. Below temperatures of 1500 K this mechanism is not active anymore due to the high activation energy. The slight emission in NO in the case of fuels with high CH₄ in the strain close to extinction may be due to the prompt mechanism.

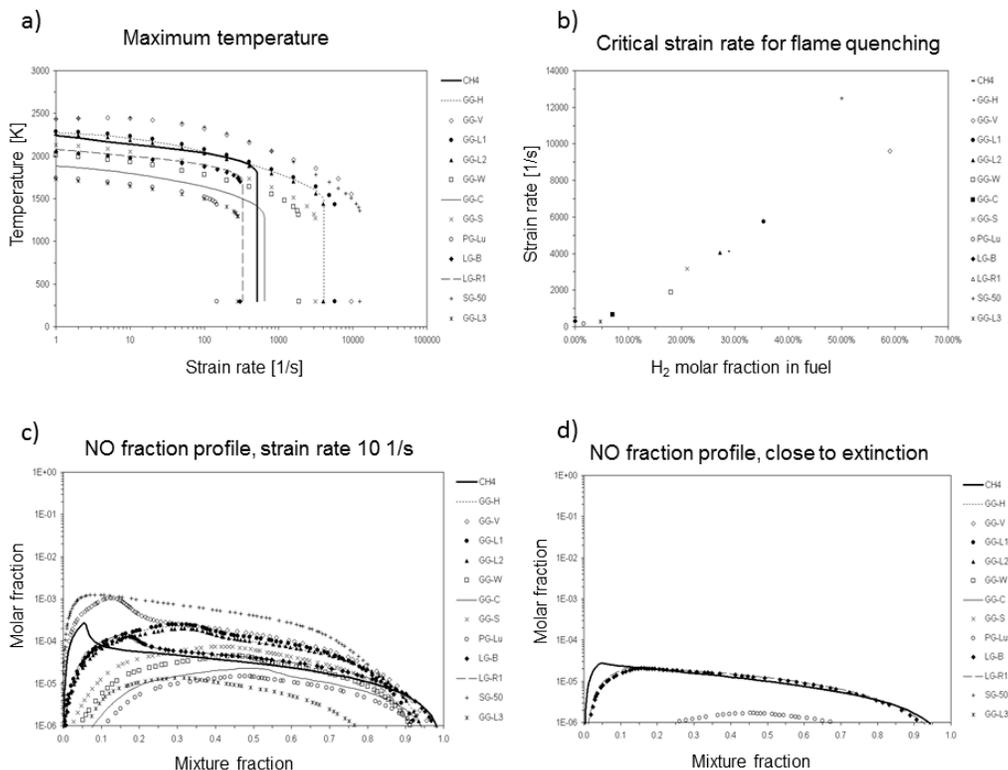


Figure 2. a) Maximum flame temperature vs. strain rate. b) Critical strain rate for quenching vs. H₂ content in fuel gas. c) NO molar fraction profile (strain rate 10 1/s). d) NO profile (strain rate close to extinction).

References

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- [2] Dixon-Lewis, G., David, T., Gaskell, P. H., Fukutani, S., Jinno, H., Miller, J. A., Kee, R. J., Smooke, M. D., Peters, N., Effelsberg, E., Behrendt, F., Warnatz, J., Calculation of the Structure and Extinction Limit of a Methane-Air Counter-flow Diffusion Flame in the Forward Stagnation Region of a Porous Cylinder. *Proceedings of the Combustion Institute* 20(1) (1985) 1893-1904 (1985)