Laser Ignition of Quiescent and Flowing Methane/Air-Mixtures under Elevated Pressures Using a Passively Q-Switched Laser

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Abstract: A passively Q-switched laser ignition system is applied to ignite quiescent and flowing methane/air-mixtures under elevated pressures. Special emphasis lies on lean mixtures. The effective focal length of the focusing line is varied to change the focal point properties.

1. Introduction

In many engine applications, a reliable ignition is important. Misfires have to be avoided because of safety reasons or emission limit values. In many applications, laser ignition is a potential candidate for a future reliable ignition system. Among others, laser ignition has been tested in cryogenic rocket engines [1] and aeronautic combustion engines [2] but also in large gas engines [3] or small reciprocating engines [4] in order to improve the ignition.

A laser ignition system consists of a laser and a focusing line. Hence, the ignition process can be influenced by both laser and focusing properties. The purpose of this study is the investigation of the influence of different laser pulse energies and effective focal lengths on the ignition and combustion of lean quiescent and flowing methane/air-mixtures. The experiments are carried out with a passively Q-switched laser ignition system in an optically accessible constant volume combustion chamber (CVCC, Fig. 1) at an initial pressure of 10 bar. More details about this system are given in Ref. [5]. The laser pulse energy is varied in the range of 3.0 mJ and 6.2 mJ (pulse width FWHM ≈ 2.5 ns). Furthermore, effective focal lengths of the focusing line between 9.6 mm and 24.6 mm are applied by changing the lens distance of a concave and a convex lens. A swirl flow is initiated by injecting a premixed methane/air-mixture under high pressure into the CVCC. Flow velocities up to 10.8 m/s are applied in this study.

The results of the experiments show that the combustion process of a quiescent methane/air-mixture can be influenced by the pulse energy and the effective focal length. In the presence of a flow, its influence seems to be stronger than different pulse energies or focal lengths. However, the ignition probability near the lean-burn limit can be improved by increasing pulse energies and effective focal lengths.

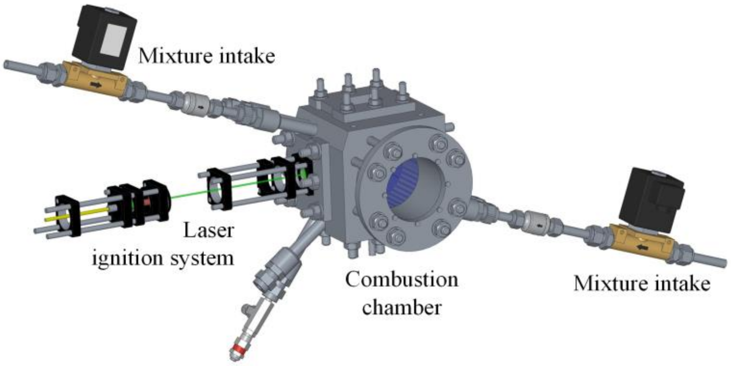

Fig. 1. Experimental setup of the combustion chamber

2. Ignition of quiescent methane/air-mixtures

In a first step, quiescent methane/air-mixtures are ignited at an initial pressure of 10 bar. In Fig. 2a, pressure traces of combustions with different pulse energies are shown. An effect of the pulse energy at an air/fuel-equivalence ratio λ of 1.2 on the combustion cannot be observed. However, a faster pressure rise after the ignition can be noticed at λ = 1.4. High pulse energies seems to increase the flame velocity and to shorten the combustion duration at very lean mixtures.

Fig. 2b displays the pressure traces after the ignition with a pulse energy of 3.0 mJ and the variation of the effective focal length. It can be seen that a decrease of the effective focal length results in a faster pressure rise and a higher maximum pressure. This is attributed to a higher energy density in the focal spot in case of short focal lengths leading to a larger initial flame kernel and a faster flame kernel growth.

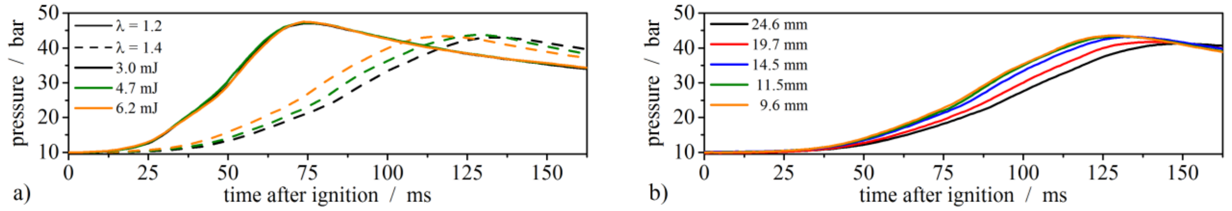

Fig. 2. Comparison of pressure traces after laser ignition (a) with various pulse energies, f_{eff} = 14.5 mm at λ = 1.2 and λ = 1.4 and (b) with a pulse energy of 3.0 mJ and various effective focal length at λ = 1.4.

3. Ignition of flowing methane/air-mixtures

In a second step, the influence of pulse energy and different effective focal lengths on flowing methane/air-mixtures is investigated. Pressure traces of combustion after the ignition by a 4.7 mJ and a 6.2 mJ laser pulse at flow velocities in the range of 1.8 m/s to 10.8 m/s are given in Fig 3a. A significantly shorter combustion duration and a higher maximum pressure can be noticed in the presence of a flow. However, the pulse energy has no effect on the combustion at flow velocities of 1.8 m/s and 5.4 m/s. The impact of the flow seems to be stronger than differences in the pulse energy. Considering a flow velocity of 10.8 m/s, a sharper pressure rise and a higher maximum pressure occurs after the ignition with a 6.2 mJ laser pulse in comparison to the ignition with a 4.7 mJ laser pulse. This is attributed to a more intense and complete combustion due to a higher energy density in the focal spot. Fig. 3b presents the results of an effective focal length variation at different flow velocities. In the pressure traces, no significant difference is observed. In this case, too, the effect of the flow apparently exceeds than changes of the effective focal length.

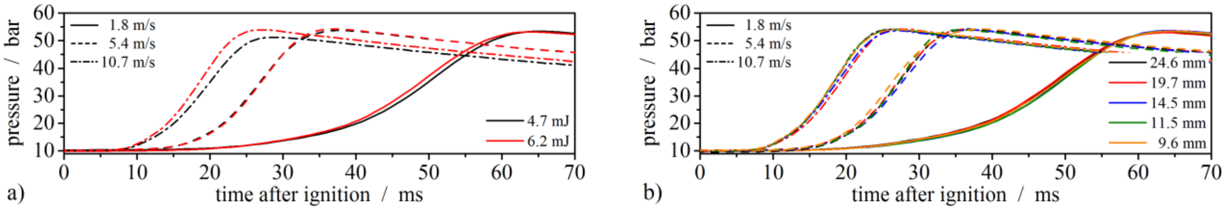

Fig. 3. Pressure traces after laser ignition (a) with pulse energies 4.7 mJ and 6.2 mJ and (b) with a pulse energy of 6.2 mJ and different effective focal lengths at various flow velocities and λ = 1.4.

Ignition tests near the lean-burn limit shows that the ignition probability can be improved by decreasing the effective focal length. This is observed for the ignition of a quiescent and a flowing mixture. The better ignition probability of short effective focal lengths at very lean conditions is attributed to the higher energy density in the focal spot.

4. Acknowledgments

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5. References

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