international journal of hydrogen energy 40 (2015) 1229–1243

Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/he

Operational issues in premixed combustion of hydrogen-enriched and syngas fuels

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ARTICLE INFO

Article history:
Received 18 September 2014
Received in revised form
4 November 2014
Accepted 6 November 2014
Available online 4 December 2014

Keywords:
Flashback
Blowout
Combustion instabilities
Hydrogen-enriched fuel
Syngas
Premixed flames

ABSTRACT

The growing interest in the use of syngas, as a means to reduce fossil fuel consumption and CO_2 emissions, has promoted many works focused on evaluating their combustion characteristics before their use in existing combustors, generally optimized for conventional fuels. Although the effect of fuel composition on the stability range (flashback and blowout) has been analyzed in a wide number of previous studies, much less attention has been devoted to other issues, such as the relation between flashback and combustion instabilities. The present work is, therefore, focused on analyzing the main concerns in syngas combustion: stability range, combustion instabilities and pollutant emissions, also specifically addressing the relation between pressure fluctuations and flashback appearance.

The results obtained revealed that the fuel composition has an important effect on the stability range, especially on flashback appearance. However, different trends were observed not only as a function of composition but also as a function of burner configuration. As a consequence, although some approximations, such as the definition of a critical Damköhler number, seemed to give quite accurate predictions of the stability range for a certain range of fuels or configurations, a thorough analysis should be made for each fuel composition before using it in a given burner configuration. In addition, in fuels with high hydrogen content, under certain circumstances, evidence of the existence of a triggering mechanism between pulsating flashback episodes and thermo-acoustic instabilities was found. This result has a high practical importance since, although thermo-acoustic instabilities had been analyzed in methane flames throughout many previous works, their appearance in syngas flames, where they can be also triggered by flashback events, was clearly less tested. Finally, the effect of fuel composition on pollutant emissions has been also analyzed.

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http://dx.doi.org/10.1016/j.ijhydene.2014.11.042

Introduction

During the last years, the growing need of reducing emissions, especially of CO_2, and finding a substitute to traditional fuels, have increased the interest in the use of a new type of fuels, commonly called syngas. Although, historically, the word 'syngas' was used to designate the mixtures of hydrogen and carbon monoxide produced from the gasification of solid fuels, such as coal or biomass, the term syngas is now used to designate gaseous fuels obtained from different sources, such as waste gasification, steam reforming of natural gas, biogas (e.g., gas from landfill or sewage, anaerobic digesters …) or waste products from other industrial activities, such as the refinery gas. Due to their different possible sources, syngases are mixtures of different components (mainly methane, carbon monoxide, carbon dioxide and hydrogen) in an extremely wide range of proportions.

Since syngas compositions are very different from those of conventional fuels, a thorough analysis of their particularities should be made before using these alternative fuels in the current combustion systems, which, in general, have been optimized for conventional fuels. A large number of previous works [1–12] have been focused on describing the combustion behavior of syngas fuels. Apart from the various effects of fuel composition on flame properties, special attention has been paid to eventual consequences on flame stability, which normally constitutes the most critical operational issue in practical combustion systems. The operating range of premixed flames, defined by flashback and blowout limits, has been studied in many previous works, showing how some of the components of syngases, especially H_2, have a strong influence on the stability range of practical flames [2,3,5–7]. In fact, although the hydrogen content seems to make the flame more prone to flashback, it also substantially enhances the resistance to blowoff, so hydrogen addition has been proposed as an effective means to reduce the lean blowout limit in lean premixed burners [9,11,13,14].

Apart from hydrogen, syngas fuels usually have a high content of carbon monoxide which also contributes to move the stability range toward leaner conditions [5–8]. It must be noted that CH_4, CO and H_2 have very different transport properties and flame speed which affect the flame behavior. For example, H_2 and CO produce flames with high temperatures and propagation speed, permitting the operation at very low equivalence ratios, which has many advantages in terms of pollutant emissions. However, the greater trend to flashback of this kind of fuels supposes a serious safety risk since the fuel nozzles and other elements located upstream of the combustion chamber are not designed to withstand flame temperatures. As a consequence, several authors have focused on analyzing the mechanisms of flashback [1,15–17] and blowout [2,3,7] with the aim of relating them to fuel composition and operating variables or geometrical characteristics of the combustors.

Although syngas flames have been the focus of a wide number of previous researches, further work is still needed in order to develop a comprehensive database which could help to predict the behavior of different syngas fuels as a function of their composition. Therefore, this work is focused on the analysis of syngas combustion in swirl-stabilized turbulent flames, one of the simplest geometries that could be considered representative of realistic systems. In particular, the main goal of this work is studying some of the most relevant operational issues, i.e., stability range (blowout and flashback), thermo-acoustic instabilities appearance and pollutant emissions for different syngas compositions and their comparison with methane, as the conventional fuel.

Experimental facility

The experimental data shown in this study were collected from atmospheric, swirl-stabilized, turbulent, premixed flames in the combustion rig shown in Fig. 1.

A quartz tube, of 120 mm of internal diameter and 230 mm of length, configured the combustion chamber that allowed unrestricted optical access to the flame. The flame was stabilized by the swirling motion of the fuel-air mixture (axial swirler with six 30° vanes) and the sudden expansion at the dump plane. The fuel-air mixture was injected at ambient temperature through an annular duct with outer and inner diameters of 40 and 25 mm, respectively. The different fuel mixtures were prepared on-line in a blending facility with computer-controlled regulation of CH_4, H_2, and CO feeding rates, which were measured with thermal mass flow meters installed in the respective lines. The air flow was fed into a plenum, connected with the premixing duct, where the fuel was injected through 12 orifices of 0.6 mm uniformly distributed in the 40 mm duct. Both air and fuel injectors operated in choked conditions in order to avoid flow rate oscillations due to strong pressure fluctuations in cases of unstable flames.

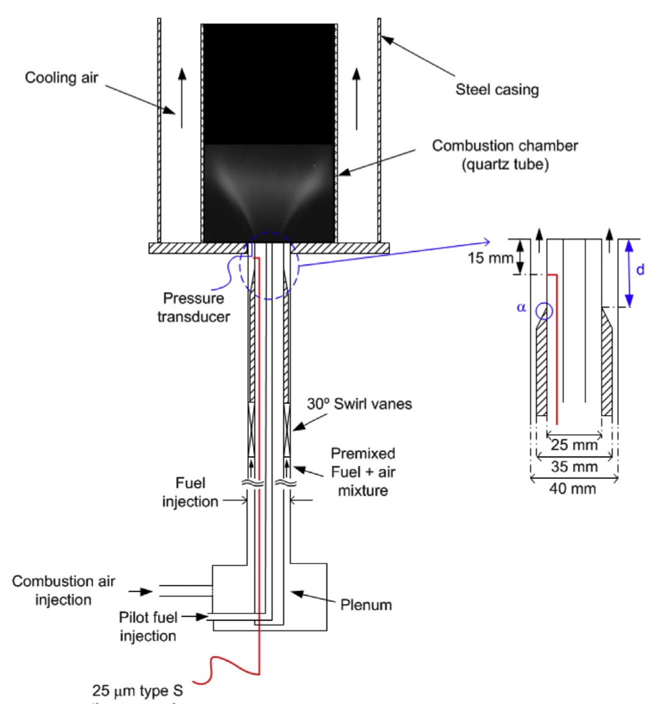

Fig. 1 – Schematic drawing of the combustion rig. Right: detail of the insert installed on the central gun.