Flame Speed Characteristics of Syngas (H₂-CO) with Straight Burners for Laminar Premixed Flames

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Abstract
Laminar flame speeds of undiluted syngas (H₂/CO) mixtures have been studied at atmospheric conditions using chemiluminescence and schlieren techniques for a straight cylindrical burner apparatus. A wide range of mixture composition, from pure H₂ to 1/99 % H₂/CO, has been investigated for lean premixed syngas flames. To achieve a better flame stabilization and reduce flame flashback propensity, two nozzle burners of different sizes have been designed and fabricated for further studies. Laminar flame speeds of various syngas mixtures are compared to results from predictions of recent syngas mechanisms.

Introduction
Synthetic gas, better known as “syngas”, has been widely studied because of its numerous industrial applications: chemicals and gases synthesis, methanol production [1], alternative fuel for spark-ignition engine [2], etc.

One of the most promising and active research areas at the moment is certainly the power generation with the development and optimization of Integrated Gasification Combined Cycle (IGCC) plants. Processes of gasification allow a wide range of solid combustibles, including coal, biomass and municipal solid wastes (M.S.W.) to be converted into syngas mixtures that will be used in a gas turbine engine to generate electricity. In this paper, syngas is considered as an alternative fuel, as its production and combustion involve a considerably clean conversion of solid fuels into energy: gas clean up, sulphur removal, CO₂ capture along with lean premixed combustion in modern gas turbine combustors are the key answers for demanding environmental standards [3-4].

One of the particular concerns, however, is the variability of syngas composition recorded in the industry. Some IGCC project shows H₂/CO ratios between 0.33 and 2.36 by volume [5]. Studies on syngas production from coal have shown that parameters such as coal quality and origins, reaction temperatures in gasifiers, oxygen/coal ratio or steam/coal ratio have an important impact on the composition of the synthesised syngas [6]. Clearly, a strong flexibility is expected while designing the new generation of IGCC power plants, particularly for the hardware related to syngas combustion. Modern combustors, for example, will have to deal with various syngas and hydrogen-enriched fuels, which requires a better understanding of their combustion complexities [7]. Phenomena, such as autoignition, flame flashback and combustion instabilities still have to be better understood in order to generalize the use of syngas by designing safer facilities [8]. The knowledge of flame speed of such mixtures is therefore highly required. This study proposes a systematic investigation of laminar flame speeds of pure H₂/CO syngas mixtures at atmospheric conditions.

Few studies related to laminar flame speeds of H₂/CO mixtures are available in the literature. Furthermore, most of them have investigated a very limited number of syngas compositions for equivalence ratios not always representative of lean premixed combustion in a gas turbine engine. Studies of flame speed were performed by Scholte and Vaags [9,10] for rich H₂/CO mixtures on a nozzle burner using the schlieren method. An identical diagnostic was used by Günther and Janisch [11] on a straight burner to study syngas mixtures at stoichiometric conditions. Yumlu [12] measured adiabatic burning velocities of various hydrogen/carbon monoxide mixtures for an equivalence ratio of 0.6, using a flat flame burner with direct cooling. Flame speeds were obtained by extrapolation to zero heat loss of burning velocities obtained for different gas flow rates. Vagelopoulos and Egolfopoulos [13] investigated laminar flame speed and extinction strain rates of hydrogen and carbon monoxide mixtures using the counterflow, twin-flame technique along with laser Doppler velocimetry. McLean et al. [14] and Brown et al. [15] reported flame speeds obtained with the constant-pressure expanding spherical flame method, followed very recently by Sun et al. [16] for pressures up to 40 atm. Laminar flame speed and stretch effects were studied by Hassan et al. for pressures between 0.5 and 4 atm [17]. Huang et al. [18] performed flame speed measurements of a pure reformer gas (28% H₂, 25% CO and 47% N₂ by volume) at atmospheric conditions using digital particle image velocimetry and the counterflow twin flame apparatus. Natarajan et al. [19] investigated the influence of CO₂ addition and reactant preheating on laminar flame speeds of syngas mixtures obtained by the cone surface method based on broadband chemiluminescence. Flame speeds near extinction have been studied very recently by Love et al. [20] and Subramanya and Choudhuri [21] on a water-cooled nitrogen-stabilized flat flame and a twin flame counterflow burner respectively.

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