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Numerical simulations of steady perforated-plate stabilized Syngas air pre-mixed flames

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ABSTRACT

Numerical investigations of steady, laminar premixed Syngas-air flames are presented in this paper. Three-dimensional simulations were performed to examine the impact of operating conditions on steady state characteristics of perforated burner flame. A detailed H_2–CO reaction mechanism having 12 species and 38 reactions was used for combustion modelling. The three dimensional simulation results are validated against the 1D flat flame result using PREMIX. Effects of inlet velocity, fuel composition and equivalence ratio on flame stability were examined. A clearly identified recirculation zone was present above the top surface of the burner plate in the case of 50% H_2-50% CO Syngas mixture. The strength recirculation zone was diminishing with the increase in percentage of hydrogen in the Syngas mixture, and the flame has stabilized closer to the top surface of the burner plate. The flame stand-off distance is found to decrease with increase in inlet velocity. Effect of increase in H_2 fraction in Syngas has less effect on flame height at higher H_2 fractions.

Introduction

The limited reserve of fossil fuels challenges to produce energy from renewable resources. Hence, the use of biomass or biomass derived fuels as a substitute for fossil fuel is of great importance. Syngas (which consists of mainly carbon monoxide, hydrogen, N_2 and CO_2) and biogas (which consists of methane and CO_2) are potential alternative fuels derived from biomass [1]. Moreover, the replacement of fossil fuel with Syngas minimizes the environmental pollution to a large extend [2]. It is of this reason, that Syngas is used in place of conventional fuels in many applications. Syngas is produced by gasification of coal or biomass. The composition of Syngas varies significantly, based on type of biomass used, gasification process, cleaning process etc. Also, lean premixed combustion technique proves to be more efficient compared to that of diffusion flame techniques in IGCC (Integrated Gasification Combined Cycle) systems [3]. In lean premixed combustion, fuel and air are well mixed before it gets transferred to the combustion region. In order to use premixed flame combustion, detailed understanding of stabilization of flames is necessary.

In the last decade, usage of Syngas gained popularity and has been used in internal combustion (I.C) engines [4–8], combustors [9,10], gas burners [11–14] etc. In compression ignition engine, Syngas can be used as dual fuel. The use of Syngas as single fuel in spark ignition (S.I) engine is also very

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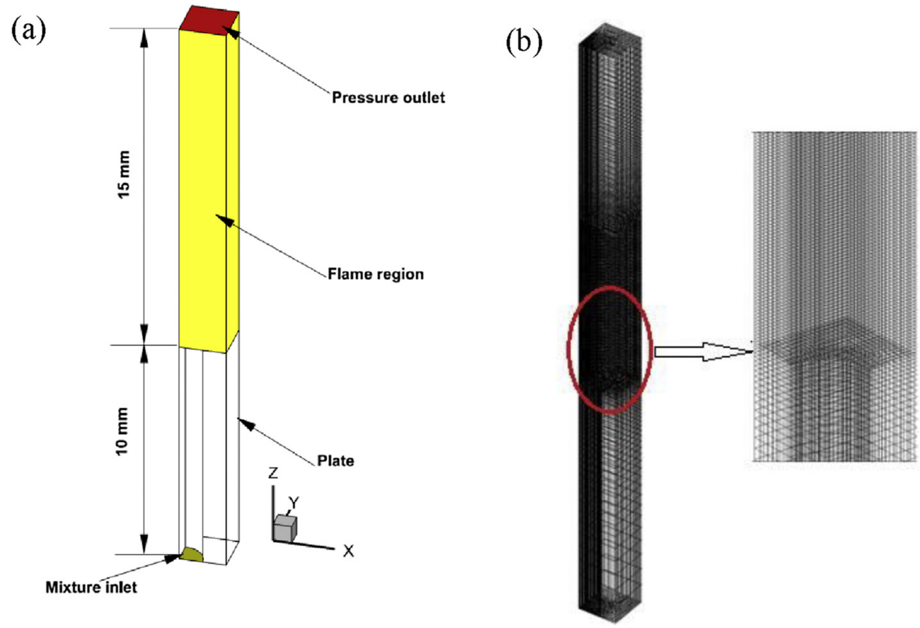

Fig. 1 – (a). The schematic diagram showing the computational domain. (b). Computational grid used in the present work.

promising. The effect of combustion features like calorific value, laminar flame speed, and flammability limits of Syngas in I.C engines were studied by Hagos et al. [15]. It is reported that dual-fuel engines acquire low emission levels, smoother and quieter operation, longer engine life and fuel savings [16–19]. The development of Syngas burners for steady flowing combustors such as gas turbines, boilers and furnaces were examined by Lieuwen et al. [20], in which the scientific issues affiliated with the operation of such combustors like blow off, flashback, combustion instability, auto ignition have been described. Recently, Syngas is used as an alternative fuel in household appliances [21]. Flashback tendency and higher gas flow rate of Syngas prompt the usage of Syngas lean premixed combustion systems in current premixed combustion systems [22]. Compared to other hydrocarbon fuels, Syngas shows unique combustion characteristics because of the variation in hydrogen concentration in Syngas mixtures. The variation in hydrogen concentration induces combustion instability in Syngas burner flames. Therefore, the detailed understanding of fundamental combustion characteristics is required for the effective utilization of Syngas as an alternate fuel. For this reason, in this paper, flame stabilization characteristics of premixed Syngas burner flames are studied.

In small scale burners, such as burners used in household applications, premixed combustion system is commonly employed. Most of the household burners are perforated plate burners in which conical shaped laminar premixed flames are stabilized downstream of the plate. The combustion characteristics such as flame–wall interaction, flashback and lift-off for this kind of burners have been studied by several researchers [23–25]. Ducruix et al. [23], analysed the effect of flame wall-interaction and flame acoustic interaction. By using a one step model of methane-air combustion, Mallens & de Goey [26] studied the stabilization characteristics of a tube and slit burner flame. M and V shaped flames on a double slit burner were also examined by Mallens et al. [27]. They found that single step reaction mechanism could not predict the flame structure exactly. Two dimensional numerical

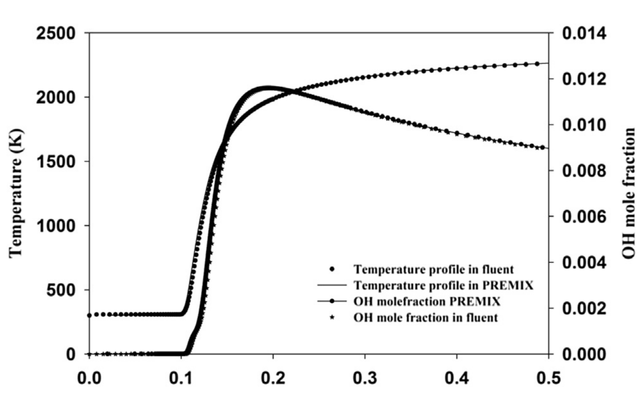

Fig. 2 – Comparison of 3D porous burner simulation results with PREMIX.

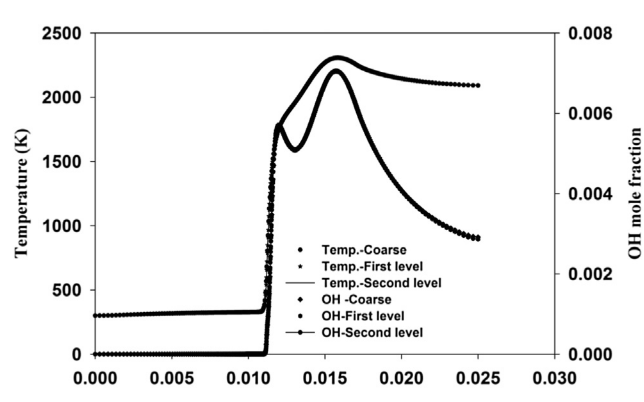

Fig. 3 – Comparison of temperature and OH mole fraction profiles of coarse, first and second level adaptation.