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Laminar burning velocity with oxygen-enriched air of syngas produced from biomass gasification

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ABSTRACT

Several studies on the laminar burning velocity of syngas mixtures have been conducted by various researchers. However, in most of these studies, dry air was used as the oxidizer, whereas very few studies have been conducted on syngas combustion in oxygen – enriched air. In this work, a numerical and experimental study on the laminar burning velocity of a mixture of H_2, CO and N_2 (20:20:60 vol%) was performed using air enriched with oxygen as the oxidizer, varying the oxygen content from 21% up to 35% for different equivalence ratios. Numerical calculations were conducted using three detailed reaction mechanisms and transport properties. Flames were generated using contoured slot-type nozzle burners, and Schlieren images were used to determine the laminar burning velocity with the angle method. The experiments were performed under the conditions of Medellin (1550 m.a.s.l.), 0.838 atm and 298 K. The laminar burning velocity increases with the concentration of the oxygen in the mixture due to the increase of the reaction rate; for a stoichiometric mixture, the laminar burning velocity increases by almost 25% with an increment of 4% of oxygen in the oxidant. However, the flammability limits also increase, allowing stable flames to exist in a wider range of equivalence ratios.

1. Introduction

The increase of the global demand for energy in recent years and the limited reserves of fossil fuel and its contribution to global warming have created the need to search for new energy resources. Alternative fuels such as synthetic gas (syngas), which is obtained from the gasification of coal and biomass, is considered one of the most promising of such resources. In Colombia, this type of fuel will play an important role as a source of energy due to the high reserves of carbon and the extensive availability of organic waste and biomass. Among the energy sources for syngas, biomass has a high potential due to its renewability and will contribute to the energy needs of the modern world [1–5]. However, the gasification of biomass has the advantage that it can be installed on a small scale to generate energy locally, eliminating transport costs and making this a good alternative to combustion at the site. The gasification process produces a low-energy content gas through an incomplete combustion process; the gas produced is mainly composed of H_2 and CO and also contains N_2, CO_2 and small quantities of CH_4 and H_2O [6]. With this kind of fuel, CO_2 and other pollutant emissions

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such as unburned hydrocarbons are considerably reduced due to two aspects, the content of hydrogen in the syngas mixture and the use of cleanup methods after the gasification process [5,7,8]. However, the gases produced during biomass gasification may have the problems of extinction and blow out by the high content of inert material, which reduces the heat release and the burning velocity [5] and can generate explosions due to stability problems generated by H_2 and CO [9], which limit its industrial application.

Oxygen enhanced combustion (OEC) is a good technique to improve the combustion process because of the benefits obtained due to the reduction of N_2, which acts as a diluent in the mixture and dilutes the reactive oxygen and the absorbed energy due to its high heat capacity, reducing the combustion efficiency [10]. Syngas combustion with enriched air increases the laminar burning velocity and flammability limits significantly due to the content of hydrogen in the mixture fuel and the higher reactivity of fuels in oxygen-enriched atmospheres. Salzano et al. [11] found that the laminar burning velocity increases by an order of magnitude when the content of oxygen in the oxidizer is increased from 21% to 60% for a fuel mixture of 30% H_2, 30% CO and 40% CO_2 and 40% H_2, 20% CO and 40% CO_2 in stoichiometric and rich conditions; however, they do not report data for lean mixtures, which are very important for industrial applications. This combination may be promising in industrial applications; however, this combination has been little studied and has not been characterized. Specific studies on OEC with gas obtained from biomass gasification have not been reported. Thus, it is necessary to conduct a study with the purpose of analyze the behavior of the gas obtained from biomass gasification with OEC, to allow for a subsequent design of efficient combustion systems for this mixture.

The laminar burning velocity (S_L) is defined as the flame propagation velocity of a one-dimensional flat flame, steady and unstreched flame [5,6].The laminar burning velocity is one of the most important parameters because it contains the physico-chemical information of the mixture, and many premixed flame phenomena, such as extinction, flash back, blowoff and turbulent flame propagation, can be calculated with this quantity as a reference parameter [8]. However, the measurement of the laminar burning velocity is also important for the development, improvement and validation of the chemical kinetic mechanism of unconventional fuel mixtures [12], such as that of syngas and oxygen enriched air. However, the real flames are affected by various factors such as curvature, stretch and heat losses; for this reason, it is necessary to use other types of flames for the measurements. The burning velocities of syngas – air premixed flames and the combustion air enriched with other fuels have been studied in the past using two measurements methods such as, the spherical bomb method and the burner stabilized flame method [5,6,13,14].

2. Methodology

2.1. Gas composition and enrichment levels

Typical composition ranges of syngas obtained from the gasification of biomass using air like oxidizer are shown in Table 1.

Table 1 – General composition of syngas obtained from the gasification of biomass[8].

Nitrogen	50–60%
Monoxide of carbon	17–32%
Dioxide of carbon	1–15%
Hydrogen	4–20%
Methane	0–3%

Based on this information, the composition determined was 20% H_2, 20% CO and 60% N_2, which adequately represents the gas produced during the gasification of biomass according to the literature [8,15]. The following expression was used to determine the level of enrichment [14]:

$$\Omega = \frac{Q_{O_2}}{Q_{O_2} + Q_{N_2}} \tag{1}$$

Where Q_{O_2} is the total content of oxygen and Q_{N_2} is the total content of nitrogen in the oxidizer flow. There are three common operating regimes. The regimes are generally referred to as low-level enrichment ($\Omega < 0.3$), medium-level enrichment ($0.3 < \Omega < 0.9$) and high-level enrichment ($\Omega > 0.9$). The first level of enrichment is commonly used in retrofit applications, where only a few modifications must be made to the existing combustion equipment. It is used when only incremental benefits are required[16]. For this reason, the level of enrichment was selected from a range of $0.21 < \Omega < 0.35$. In this study, measurements were performed up to an equivalence ratio of 2.0 in most of the mixtures.

2.2. Experimental methodology

The experiments were carried out generating flames in two burners with contoured slot-type nozzles with sizes of

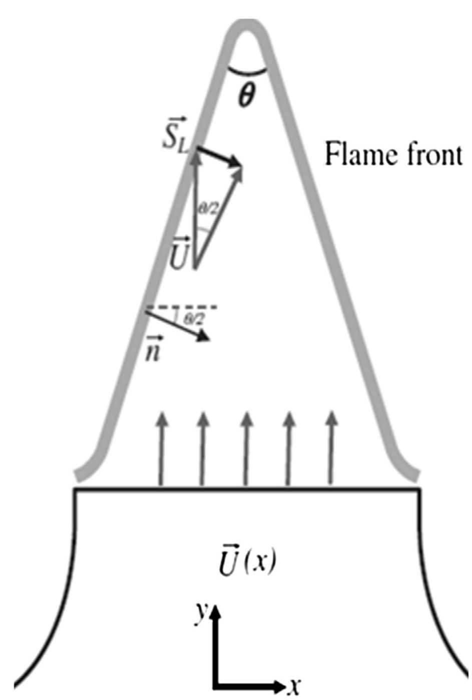

Fig. 1 – Burner stabilized flame technique (angle method).