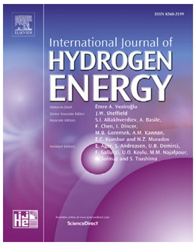
INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2017) 1–7

Available online at www.sciencedirect.com

ScienceDirect

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



Effect of the addition of H_2 and H_2O on the polluting species in a counter-flow diffusion flame of biogas in flameless regime

Hadef Amar [a,*], *Mameri Abdelbaki* [a], *Tabet Fouzi* [b], *Aouachria Zeroual* [c]

[a] *Faculté des sciences et sciences appliquées, Département de Génie Mécanique, Université Larbi Ben Mhidi, Oum El Bouaghi, BP 358, 04000, Algérie*

[b] *DBFZ (Deutsches Biomasseforschungszentrum gemeinnützige GmbH), Torgauer Straße 116 D-04347, Leipzig, Germany*

[c] *Laboratoire de Physique Energétique Appliquée, Université de Batna1, 05000 Algérie*

ARTICLE INFO

Article history:
Received 27 January 2017
Received in revised form
18 October 2017
Accepted 23 November 2017
Available online xxx

Keywords:
Biogas-hydrogen blend
Dilution by H_2O
MILD combustion
H_2O thermal and chemical effects

ABSTRACT

Biogas is obtained by fermentation of biomass, it is a renewable fuel and practically CO_2 neutral, offers a significant advantage compared to other fuels for its low carbon/hydrogen ratio (1 atom of carbon and 4 hydrogen atoms). Thus, the level of CO_2 emissions from biogas is lower than that of the other fuels. Biogas is a biodegradable and renewable fuel; its benefits are conjugated especially in a flameless combustion process that significantly reduces fuel consumption and polluting emissions. In this paper, we study the effects of the dilution of a mixture of the biogas BG75 (75% CH_4 and 25% CO_2) – hydrogen by a volume of water vapor ranging from 10% to 50%. The configuration of an opposed jet flame is used with a constant strain rate of 120 s^{-1}. The chemical kinetics is described by the Gri3.0 mechanism. It has been found that the combustion structure is very sensitive to the various parameters.

Introduction

In order to improve the combustion process, two related areas are emphasized, improving energy efficiency and reducing pollutant emissions. Although they are originally linked to the fuel use issue, these two dimensions are not tackled in a related way unless recently. Indeed, the issue of energy efficiency has always been a researcher's concern; however, it was necessary to await the realization of the first studies on the combustion releases and their impact on the environment.

The use of the lean combustion leads to a low production of polluting species with an unstable flame that is critical to industrial applications. To overcome this problem, the hydrogen known for its high calorific value and its reactivity is added to lean mixtures. Another approach uses low calorific value (LCV) fuels such as biogas to reduce emissions and to increase energy efficiency. Recent studies have shown that the addition of hydrogen to biogas is as advantageous as its addition to lean hydrocarbon mixtures [1,2].

The wish to reduce pollutants leads specialists in energy conversion devices such as internal combustion engines, stationary or mobile gas turbines to promote their products in a way to minimize the production of polluting species. One of the used techniques is to dilute the fuel by recirculating combustion products among others CO_2 and H_2O [3–5], which

---

* Corresponding author.
E-mail address: hadef_am@univ-oeb.dz (H. Amar).

https://doi.org/10.1016/j.ijhydene.2017.11.159

Please cite this article in press as: Amar H, et al., Effect of the addition of H_2 and H_2O on the polluting species in a counter-flow diffusion flame of biogas in flameless regime, International Journal of Hydrogen Energy (2017), https://doi.org/10.1016/j.ijhydene.2017.11.159

play a dominant role in terms of quantity and physicochemical properties on flame stabilization and the combustion quality in fireplaces [6].

To increase the reduction of polluting species, a flame-free combustion regime also known as MILD (Moderate or Intense Low-oxygen Dilution) is used. It is defined as a combustion regime for which no flame is visible, stable, with a very low temperature gradient and emitting very few pollutants (CO and NO).

In order to identify the area of combustion without flame. de Joannon M et al. [7,8] considered numerically the characteristics of the MILD combustion in an opposite Jet configuration of a diffusion flame $CH_4 + N_2$/air, where they studied the evaluation of the temperature and the quantity of heat released in function of the mixture fraction under different input parameters, air preheating temperature, fuel dilution, pressure and strain rate.

They have shown that a significant uniformity of the evolution of heat release is associated with air temperatures above the self-ignition temperature which is homogeneous for a characteristic time comparable to the time of a conventional combustion and *the reaction zone is thickened and become very thick*. Maruta et al. [9] studied the combustion limit and the reaction zone structure of countercurrent diffusion flames of methane diluted with nitrogen and a highly preheated oxidant.

Their results show that the extinction limits become wider with the increase of the air temperature, and when the air temperature was above 1300 K, the extinction limits disappeared. In this temperature range, combustion continues even under extremely fuel-poor conditions such as 1% methane in nitrogen. Ryugo Fuse et al. [10] studied the competitiveness of air preheating and the reduction of the oxygen quantity on the formation of the NO species of a diffusion flame in an opposite jet configuration. Their results show the adaptation of the GRI 3.0 mechanism to the simulation of the formation of NOx in MILD regime with a validation by experimental results. The authors showed that the ejection of the air at high temperature increases the formation of NO and the reduction of the oxygen content reduces it. Hamdi et al. [11] examined the effects of fuel dilution and stretch rate on the structure of the reaction zone and the formation of NOx in flameless combustion. They showed that the mass fractions of NOx decrease with increasing strain rate as well as with the dilution of methane with nitrogen.

In light of these work, which demonstrate an advanced research in flameless combustion, a contribution is added by the present work which aims to study the effect of the addition of hydrogen and water vapor to the fuel on polluting species of a laminar diffusion flame of biogas, as well as the chemical effect of water vapor on temperature and major species.

Geometric configuration and calculation strategy

The used geometry is that developed by Kee et al. [12] and Lutz et al. [13], it consists of two opposing jets, one injecting the fuel and the other the oxidizer. This configuration allows simplifying, on the one hand, the equations of the phenomenon, which become unidimensional and on the other hand to obtain a flat flame allowing the characterization of its structure.

The fuel jet is a mixture of hydrogen-enriched biogas (75% CH_4 + 25% CO_2 by vol), which varies from 0% to 20% diluted by steam from 0% to 50%, while the jet of the oxidizer refers to the preheated air with low oxygen content and atmospheric pressure ($P = 1$ atm). The distance between the two jets is $D = 2$ cm (Fig. 1) and the strain rate of the flame is $a = 120\ s^{-1}$ from which the injection velocity of the reactants for each composition of the fuel and of the oxidant [14] is calculated according to the formula:

$$a = \frac{2(-v_O)}{D}\left[1+\frac{v_F}{(-v_O)}\sqrt{\frac{\rho_F}{\rho_O}}\right] \quad (1)$$

where ν_O, ν_F ($\nu_O = \nu_F$) are, respectively, the velocities of the oxidant and the fuel, ρ_O , ρ_F represent the densities of the oxidant and the fuel and D is the distance between the two injectors. The injection temperature for the fuel is $T_F = 300$ K and for the oxidizer $T_O = 1200$ K.

The composition of the injected fuel is:

$$0.75(1-\alpha)(1-\beta)CH_4 + 0.25(1-\alpha)(1-\beta)CO_2 + \alpha H_2 + \beta H_2O \quad (2)$$

The composition of the injected oxidant is:

$$0.04O_2 + 0.17CO_2 + 0.79N_2 \quad (3)$$

where α, β are mole fractions of H_2 and H_2O added to the biogas.

The mass conservation equation in ax symmetric coordinates is:

$$\frac{\partial \rho u}{\partial x} + \frac{1}{r}\frac{\partial(\rho v r)}{\partial r} = 0 \quad (4)$$

where ρ, u and v are respectively the density, the axial velocity and the radial velocity; r and x represent the radial and axial direction.

According to Von Karman's hypothesis, the ratio v/r and the other variables are only functions of x, so the conservation equation of the momentum is written as follow:

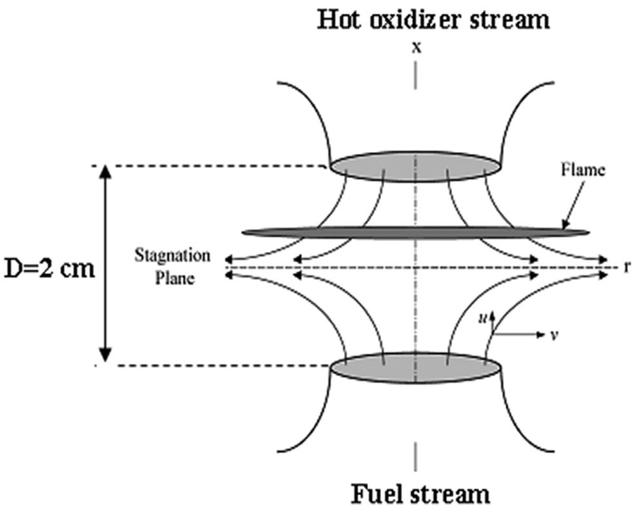


Fig. 1 – Opposed jet flow configuration.

Please cite this article in press as: Amar H, et al., Effect of the addition of H_2 and H_2O on the polluting species in a counter-flow diffusion flame of biogas in flameless regime, International Journal of Hydrogen Energy (2017), https://doi.org/10.1016/j.ijhydene.2017.11.159