18èmes Journées Internationales de Thermique (JITH 2017)
Monastir (Tunisie), 25 - 27 Octobre 2017

EFFECTS OF HYDROGEN ADDITION AND CARBONE DIOXIDE ADDITION TO THE FUEL JET ON THE VELOCITY FIELD IN REACTING FLOW

Auteurs : Ibtissem HRAIECH , Rabeb BOUGATF , Jean-CharlesSAUTET and Abdallah MHIMID

LESTE ; Ecole Nationale d'Ingénieurs de Monastir, Tunisie
ibtissemhraiech@gmail.com

Résumé:
Regulations on protection of the environment lead to develop new technologies of combustion. A new alternative fuel, mixture of natural gas (NG), hydrogen up to 20% in volume and carbon dioxide up to 50% in volume, called bio-hythane, has been created from the recovery of the waste from households and agriculture, via suitable digesters. It provides a source of renewable energy and usable, generates a better thermal efficiency and a reduction of pollutant emissions and is expected to play an important role in future energy production.
An experimental study of a reacting jet according to the hydrogen addition and the carbon dioxide dilution has been investigated. PIV technique allows deducing the instantaneous two-dimensional velocity fields. The results show that hydrogen addition increases the mean longitudinal velocities and the carbon dioxide addition reduces the mean longitudinal velocity.
The combustion decreases the entrainment of the ambient fluid and raises the viscosity of the flow, leading to an increase of the longitudinal velocity along the bio-hythane jet.

Mots clés : Hythane; Hydrogen; CO_2 dilution;; NOx; CO.

Retrait de paragraphe : 1 cm. Marges : 2,5 cm. Bas, haut, droite et gauche.

1.Introduction

A new alternative fuel is currently used in many combustion processes; it generates a better thermal efficiency and a reduction of pollutant emissions and is expected to play an important role in future energy production. Mixture of natural gas (NG), hydrogen up to 20% in volume and carbon dioxide up to 50% in volume, called bio-hythane, has been created from the recovery of the waste from households and agriculture, via suitable digesters. It provides a source of renewable energy and usable, and plays an important role in future energy production.The properties of hydrogen, specially low density, high molecular diffusivity, wide flammability limits, high flame speed, and low ignition energy (Choudhuri and Gollahalli, [1], [2]) allowed combustion systems to operate with lean fuel mixtures.
Choudhuri and Gollahalli [2] studied experimentally the effect of hydrogen addition on NOx and CO emissions of NG-H_2 turbulent diffusion flame, and showed a reduction in the soot concentration and CO emissions, but an increase in NO and NOx emissions with addition of hydrogen to the fuel.
El Ghafour et al [3] at a fixed Reynolds number (4000). They found that the addition of hydrogen ameliorates the flame stability and reduces the flame length for relatively high hydrogen concentrations. On other side, their results present an increase in NO and CO concentration.
The influence of hydrogen addition to natural gas on the flow dynamics was investigated experimentally in non-reacting flow and in combustion by Yon and Sautet [4].
Liu et al [5] carried out a numerical investigation on the chemical effect of CO_2 replacement of N_2 in air on the burning velocity of CH_4 and H_2 flames and showed that the relative importance of the chemical effect of CO_2 on the burning velocity increases as more CO_2 is added to replace N_2 in air.

Previous works have proved that the CO_2 is the best destabilize among the diluents, because the three effects (dilution>thermal>chemistry) induce loss of flame stability (CO_2 has a strongest ability to break flame stability, than N_2). [6]
Previous studies have proved that the soot formation in diffusion flames were decreases by CO addition to the coflow 2 air, resulting from the short residence time in the inception region [7-11].
The effect of CO_2 addition has studied by Dally and al [12]. They showed experimentally and numerically that CO_2 addition in a non-premixed methane/air flame decreases flame temperature by reducing reactant concentration inside the reaction zone.
Limited studies have been reported that describe the influence of hydrogen addition on flame stability and flame speed under fuel-lean condition in a swirl-stabilized flame under confined conditions at constant heat load with desired [13,14].

The present study is carried in reacting flow from a cylindrical burner to investigate the effect of the hydrogen addition and CO_2 dilution on the flow aerodynamic, the velocity profiles. The experimental setup is composed by a burner functioning with natural gas (NG) added to hydrogen and carbon dioxide.

2. Experimental section

2.1. Burner, flow control system and combustion chamber:

The present study aims to investigate the effects of the hydrogen content in fuel (NG+H_2) from α_{H2}=0% to α_{H2}=20%, and the the carbon dioxide content in mixture (NG+H_2+CO_2) ,from β_{CO2}=0% to β_{CO2}=50%,on the flow aerodynamics, the NOx emissions and the CO emissions. The burner depicted in Figure 1 consists of a jet of bio-hythane (mixture $CH_4/H_2/CO_2$). The cylindrical burner, of internal diameter d=6 mm, brings the mixture $CH_4/H_2/CO_2$ into the ambient air.

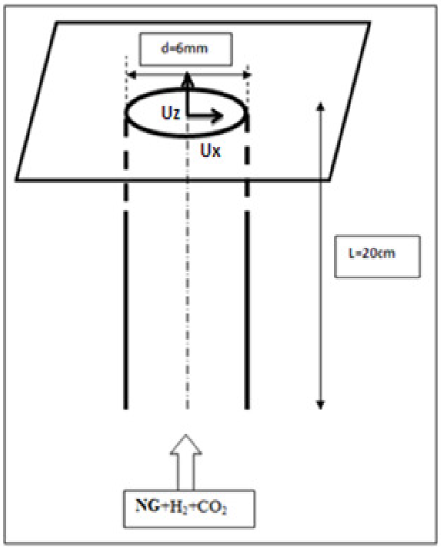


Fig.1 :Sketch of the burner

The natural gas has a density of 0.83 kg/m^3 and a volume composition of 85% CH_4, 9% C_2H_6, 3% C_3H_8, 2% N_2, 1% CO_2, and traces of higher hydrocarbon species. The hydrogen volume fraction (α_{H2}) in the fuel mixture (NG+H_2) varies between 0 and 20%**.**The fuel volumetric flow rate is Q_{vfuel}= Q_{VGN}+ Q_{vH2}. CO_2 is introduced in the fuel mixture to study the effect of CO_2 dilution. The volumic percentage of CO_2 (β_{CO2}) in the mixture (NG+H_2+CO_2) varies from 0% (no dilution) to 50%. The CO_2 flow rate is $Q_v co_2$ and the total jet flow rate is Q_{tot}= Q_{vfuel}+ $Q_v co_2$
Table. 1 summarizes the parameters of this experimental study including natural gas, hydrogen and carbone dioxide flow rates, the fuel exit velocity U_0, Reynolds Number, and the Schmidt number (Sc=υ/D where υ is the cinematic viscosity and D is the molecular diffusion coefficient).

Table 1. Gas flow characteristics

Jet Flame mixture														
Fuel mixture														
%NG (fuel)	$\%H_2$ (fuel)	$Q_v NG$ (l/min)	$Q_v H_2$ (l/min)	Qvfuel (l/min)	$\%CO_2$	$Q_v co_2$ (l/min)	Qtot (l/min)	Exit velocity U_0 (m/s)	Jet Reynolds number	ρjet	Jet Schmidt number	$\%H_2$ (total mixture)	%NG (total mixture)
100	**0**	24.09	0	24.09	**0**	0	24	14.2	6312	0.83	0.8	**0**	**100**
					10	2.6	26.7	15.7	9005	0.93	0.86	**0**	**90**
					20	6	30.1	17.7	10741	1.03	0.91	**0**	**80**
95	**5**	23.73	1,25	24.98	**0**	0	24.9	14.7	7518	0.79	0.75	**5**	**95**
					10	2.7	27.7	16.3	8959	0.9	0.78	**4.5**	**85.5**
					20	6.2	31.2	18.4	10769	1	0.83	**4**	**76**
90	**10**	23.34	2,59	25.94	**0**	0	25.9	15.3	7422	0.75	0.71	**10**	**90**
					10	2.8	28.8	16.9	8914	0.86	0.73	**9**	**81**
					20	6.4	32.4	19.1	10804	0.97	0.77	**8**	**72**
85	**15**	22.92	4,046	26.97	**0**	0	26.9	15.9	7322	0.71	0.67	**15**	**85**
					10	2.9	29.9	17.6	8868	0.83	0.69	**13.5**	**76.5**
					20	6.7	33.7	19.8	10847	0.95	0.73	**12**	**68**
					30	11.5	38.5	22.7	13486	1.06	0.79	**10.5**	**59.5**
80	**20**	22.47	5,61	28.09	**0**	0	28.1	16.5	7205	0.66	0.65	**0.2**	**80**
					10	3.1	31.2	18.4	8822	0.78	0.68	**0.18**	**72**
					20	7	35.1	20.7	10899	0.9	0.7	**0.16**	**64**
					30	12	40.1	23.6	13713	1.02	0.76	**0.14**	**56**

3. Velocity measurement

Particle Image Velocimetry (PIV), non-intrusive method, allows to procure 2-D images of the flow and the instantaneous two-dimensional velocity fields.The experimental P.I.V longitudinal component of the velocity and RMS radial setup was described in Fig. 2 The light source (120 Mj/pulse, pulse duration of 8 ns) is a double-pulsed Nd-Yag laser (Big Sky CFR200, Quantel) with a wavelength of 532 nm and a frequency of 10 Hz. An optical system consisting of three consecutive lenses creates the laser sheet with 500 µm thickness. A CCD camera (2048*2048 pixel^2, Image Pro X Lavision) with a dynamic range of 14 bits is oriented perpendicularly to the laser sheen. A convergent lens (f=85 mm), placed perpendicularly to the light source, collects the signal of Mie scattering emitted by the seeded particles. Zirconium Oxide particles (mean diameter of 10 µm) are used in reacting configurations. An interference filter is used to reject the bright luminosity in front of the lens of the PIV setup. The magnification is 0.051 mm.pixel^{-1} and the time interval between two images varies according to the investigated configurations (Table 2).

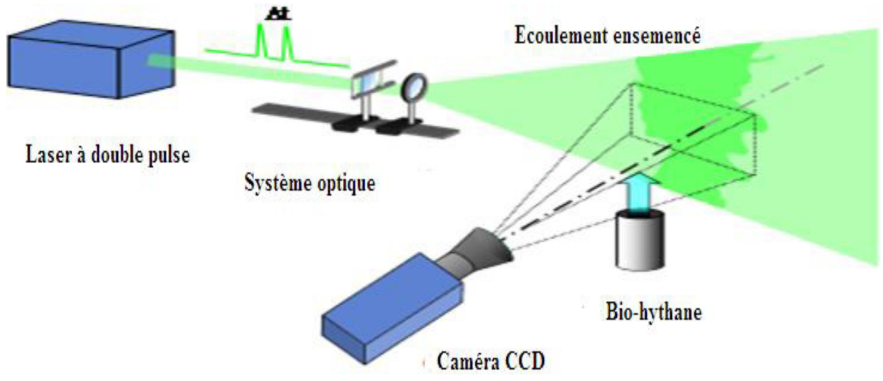


Fig.2:Particle image velocimetry experimental setup

Table2: Parameters of PIV setup

	Reacting flow		
Δt(μs)	18	45	65
Magnification (mm.pixel^{-1})	0.0051		
Explored height in the jet (mm)	0-100	100-200	200-300

From recording 500 instantaneous pairs of images, with a resolution of 2048* 2048 pixels ², a statistical processing enables to obtain the mean velocity field, for each height and configuration.
Fig. 3 displays the images of the seeded particles in reacting flow for a hydrogen volume fraction equals to 0 and Carbone dioxide Carbone volume fraction equals to 0. This allows to study the velocity radial component and the longitudinal component of the velocity and RMS radial component and the RMS longitudinal component.

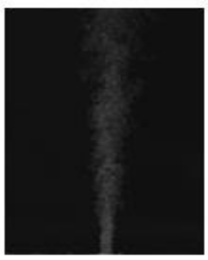
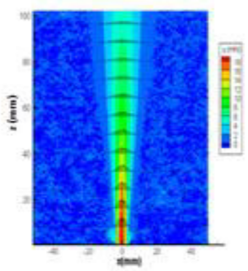
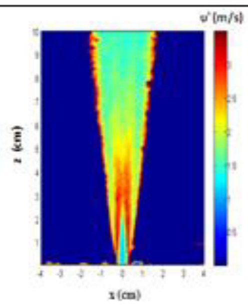
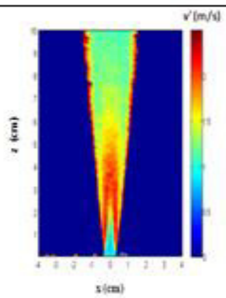
a) Images of seeded particles	b) mean velocity fields	c) rms velocity fields of the longitudinal component	d) rms velocity fields of the radial component.
			

Fig.3. a) Images of seeded particles b) mean velocity fields c) rms velocity fields of the longitudinal component d) rms velocity fields of the radial component

4. Results and discussion

In this part we will study the dynamic field of the biohythane flame to quantify the effects of hydrogen addition and CO_2 dilution. The mixture (GN + H_2 + CO_2) was seeded with zirconium oxide particles.

Figure 4 gives cartographies of longitudinal velocity vectors for configurations (α_{H2}=10%; $\boldsymbol{\beta}_{CO2}$=10%) and (α_{H2}=20%; $\boldsymbol{\beta}_{CO2}$=10%) in the reacting configuration for the different heights (0≤ Z≤ 30 cm).

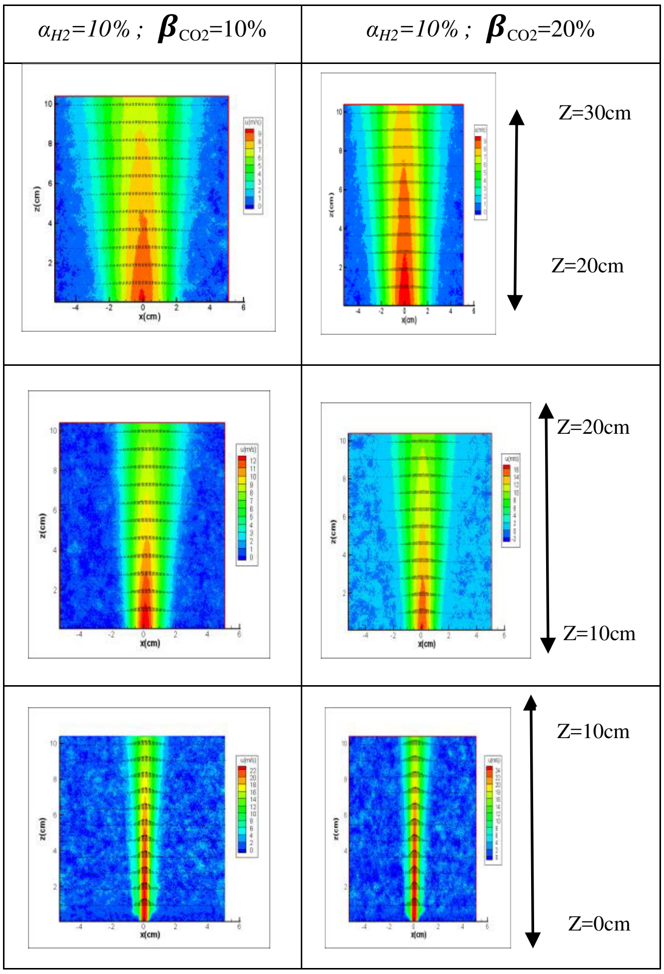
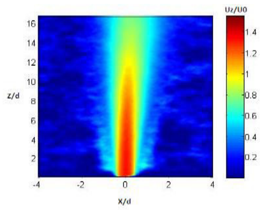
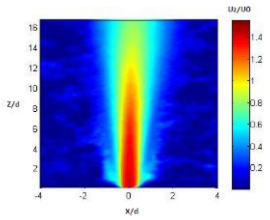


Fig.4: Mean longitudinal velocity field U in the reacting configuration

Figure 5 presents the 2D fields of normalized mean longitudinal velocity U / U0 in the XZ plane for α_{H2} = 0% and α_{H2} = 20% ,no dilution and β_{CO2} = 20% (α_{H2} = 0%) and β_{CO2} = 0% and β_{CO2} = 20% (α_{H2} = 20%) obtained in the reacting flow.
Without CO_2 dilution (Figure 5.a), adding hydrogen increases the velocity of the jet along the axis and the normalized longitudinal velocity are lower with α_{H2} = 0% in comparison with α_{H2} = 20%.
(Figure 5.b) shows that without hydrogen (α_{H2} = 0%) addition of carbon dioxide decreases the velocity along the jet.
Figure 5.c shows the combined effects of the hydrogen addition and CO_2 dilution. The effect of CO_2 is offset by the addition of hydrogen.

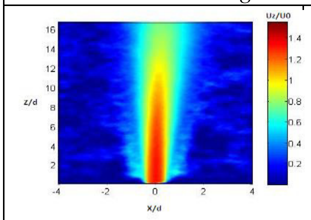
Fig.5.a. β_{CO2} *= 0%*

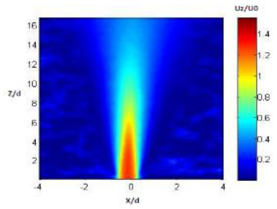




α_{H2}=0% | α_{H2}=20%

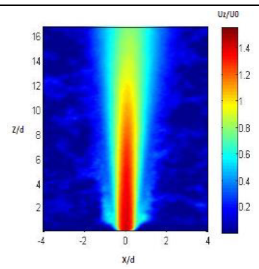
Fig 5.b. α_{H2}=0%

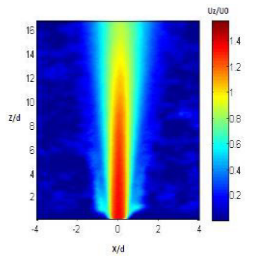




β_{CO2}=0% | β_{CO2}=20%

Fig 5.c. α_{H2}=20%





β_{CO2}=0% | β_{CO2}=20%

Fig.5. 2D field of the normalized mean longitudinal velocity, U / U0, in the XZ plane for the reacting flow.

Conclusion

The effects of hydrogen addition and carbone dioxide dilution on the velocity profiles in natural gas-hydrogen-carbon dioxide-air flames from a cylindrical burner have been experimentally studied. PIV technique allows deducing the instantaneous two-dimensional velocity fields.

The results showed that the addition of hydrogen increases the longitudinal velocity along the biohythane jet and the carbon dioxide addition reduces the mean longitudinal velocity.

Références

[1] A.R .Choudhuri, S.R .Gollahalli, Combustion characteristics of hydrogen-hydrocarbon hybrid fuels, *I. J. Hydrogen Energy*, *25*, pp.451-462, 2000.

[2] A.R .Choudhuri, S.R .Gollahalli, Characteristics of hydrogen hydrocarbon composite fuel turbulent jet flames, *I. J. Hydrogen Energy*, *28*, pp.445–454,2003

[3] S.A.A .El-Ghafour, , A.H.E. El-dein,A.A.R .Aref, Combustion characteristics of natural as-hydrogen hybrid fuel turbulent diffusion flame, *I. J. Hydrogen Energy ,35* ,pp.2556-2565,2010.

[4] S..Yon. Oxy-combustion de l'hythane dans des bruleurs à jets fortement séparés [Thèse de doctorat]. France: Université Rouen; 2013.

[5] F.S.Liu, HS.Guo, GJ.Smallwood, The chemical effect of CO_2 replacement of N_2 in air on the burning velocity of CH_4 and H_2 premixed flames, Combustion and flame, 13, pp.495-497,2003.

[6] J.Min, F .Baillot, H.Guo,E. Domingues, M .Talbaut, B .Patte-Rouland, Impact of CO_2, N_2 or Ar Diluted in Air on the Length and Lifting Behavior of a Laminar Diffusion Flame, Proceedings of the Combustion Institute,33, pp.1071-1079,2011.

[7] DX .Du, RL .Axelbaum, CK .Law,Soot formation in strained diffusion flames with gaseous additives. Combust Flame,102:11-20,1995.

[8] .Zhang, A.Atreya, K.Lee,Sooting structure of methane counterflow diffusion flames with preheated reactants and dilution by products of combustion. In: Twenty-fourth symposium (International) on combustion, 24, 1049-1057, 1992.

[9] KC.Oh, HD .Shin,The effect of oxygen and carbon dioxide concentration on soot formation in nonpremixed flames.Fuel ,85,615-624,2006.

[10] FS.Liu, HS.Guo, GJ.Smallwood, OL.Gulder,The chemical of carbon dioxide as an additive in an ethylene diffusion flame: implications for soot and NO formation. Combust Flame , 125,778-787,2006.

[11] HS.Guo, GJ.Smallwood, A numerical study on the influence of CO_2 addition on soot formation in an ethylene/air diffusion flame, Combustion Science and Technology, 180), pp.1695–1708, 2008.

[12] B.B.Dally, E .Riesmeier, N.Peters, Effect of fuel mixture on moderate and intense low oxygen dilution combustion, Combustion and Flame, 137, pp.418-431, 2004

[13] M .Karbasi, I.Weirzba, The effect of hydrogen addition on the flame stability limits of methane jet diffusion flames, Hydrogen Energy, 23,123–9, 1997.

[14] GS. Jackson, R .Sail, JM .Plaia, CM .Boggs, KT .Kiger, Influence of H2 on the response of lean premixed CH4 flames to high strained flows, Combustion and Flame,132,503–511, 2003