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EFFECTS OF CARBONE DIOXIDE DILUTION AND HYDROGEN ADDITION ON POLLUTANT EMISSION OF A TURBULENT HYTHANE FLAMES

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Abstract:
With increasing concern about energy shortage and environmental protection, improving engine fuel economy and reducing exhaust emissions have become major research topics in combustion and engine development. Hythane (a blend of hydrogen H_2 and natural gas NG) has generated a significant interest as an alternative fuel for the future. This paper describes an experimental study of the effects of CO_2 addition on the NO_x emissions and the CO emission of a turbulent jet diffusion NG-H_2 flame.
Measurements of combustion product concentrations were carried out at the combustion chamber exit using a water-cooled probe, a NO_x analyzer and a CO analyzer.
The results showed that the diluted combustion of CO_2 favors the decrease of the combustion temperature and thus reduces of nitrogen oxide emissions,also the addition of hydrogen reduces the dilution of the reactants by the products of combustion and reduces the residence time of the various products which consequently, increases the flame temperature and the thermal NOx formation.

Keywords: Hythane; Hydrogen; CO_2 dilution; NOx; CO.

1. Introduction

The decrease of fossil energy resources induces the reduction of fuel consumption and the optimization of combustion chamber performances. An 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 developed. It generates a better thermal efficiency and a reduction of pollutant emissions and is expected to play an important role in future energy production.
Dally et al. [1] investigated experimentally and numerically the effect of CO_2 addition on turbulent methane/air jet diffusion flame, they observed a reduction of flame temperature by decreasing reactant concentration inside the reaction zone with CO_2 addition.
Guo et al.[2]studied experimentally the effects of different additives to air on the lift-off of a laminar CH_4/air diffusion flame have been explored experimentally. Their results show shown that the addition of CO_2 causes flame lift-off due to the dilution, thermal and chemical effects.
The chemical effect of CO_2 replacement of N_2 in air on the burning velocity of CH_4 and H_2 flames was studied numerically by Liu et al. [3] , they found that the relative importance of the chemical effect of CO_2on the burning velocity increases as more CO_2 is added to replace N_2 in air. Min et al. [4] found experimentally 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).
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 [5-9].Mazas et al[10] investigated numerically and experimentally the effect of CO_2 and H_2O additions on laminar flame speed of oxygen-enriched

methane flame at atmospheric pressure, and showed a slight underestimation of the flame speed of CH_4/O_2 diluted with CO_2 and H_2O and these difference reduce for higher dilution rates.
Choudhuri and Gollahalli [11] performed an experimental investigation on turbulent NG-H jet diffusion flame and observed a continuous reduction in the flame length, a reduction 2 in the soot concentration and emission index of CO (EICO), but an increase in EINO with hy- drogen addition.
Bauer and Forest [12] investigated, the effect of hydrogen addition on the performance of methane-fueled vehicles. It was shown that the wide flammability limits of hydrogen makes it possible to run SI engines at lower equivalence ratios using a hydrogen–methane blend, which lowers cylinder temperature and thereby NOx emission.
Al Baghdadi [13] also observed a significant reduction in NOx production in spark ignition engines when a hydrogen–ethanol mixture was used instead of gasoline. Flame studies using hydrogen–hydrocarbon fuel blends have also been reported.
Rortveit et al. [14] reported an experimental–numerical study of NOx emissions in counterflow methane–hydrogen non premixed flames. Naha et al. [15,16] studied the emission characteristics of hydrogen–methane and - hydrogen–n-heptane fuel blends using a counterflow flame, and observed significant reduction in NOx emission in hydrogen–n-heptane flames.
The addition of hydrogen to traditional hydrocarbon fuels shows considerable promise for stable operation at ultra-lean conditions and hence reducing NOx emissions in premixed gas turbine combustors without any adverse effect on the increased emissions of CO and UHC. Even though the addition of hydrogen might increase the NO emission due to higher flame temperature at same heat load, this may be offset by the ability to burn an overall leaner mixture [17, 18].
In this context, the present study provides an experimental investigation of the turbulent biohythane-air jet in a coaxial burner. The aim is to determine the effects of carbone dioxide dilution in the fuel on pollutant emission of a turbulent hythane flames.

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.

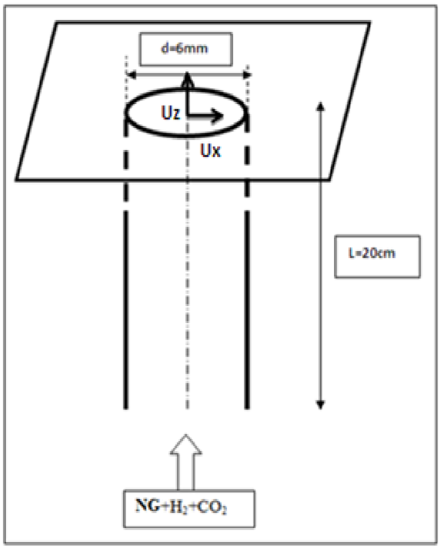

Fig.1 :Sketch of the burner

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_vco_2 and the total jet flow rate is $Q_{tot}= Q_{vfuel}+ Q_vco_2$

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 ($Sc=\upsilon/D$ 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_vNG (l/min)	Q_vH_2 (l/min)	Qvfuel (l/min)	$\%CO_2$	Q_vco_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. Measurements of NOx emissions

The measurement of concentrations of gases produced by the combustion is performed at the exit of the combustion chamber using a sampling probe. The sampled gases are led to a gas analyzer of analysis (Horiba PG-250) for measuring the concentrations of NOx , CO, CO_2 and O_2.

The analysis of the nitrogen oxides is carried out by chemiluminescence method. Introducing ozone (O_3) in the sample gas, a part of nitrogen monoxide (NO) contained in the gas reacts with the ozone oxidizes and becomes nitrogen dioxide (NO_2). Nitrogen dioxide is generated in an excited state, and returns to its original state by emitting a photon. The flow measuring photons emitted gives the concentration of NO. The accuracy of measurements on concentrations of NOx provides significant trends in NOx emissions depending on configuration.The carbon monoxide CO concentration measurements are performed the analyzer by infrared radiation using NDIR (Non Dispersive Infra Red).

4. Results and discusion

4.1. Nitrogen oxides emission

The effect of carbon dioxide dilution and hydrogen addition on the absolute nitrogen oxides emission $EINO_x$ defined by $\frac{NO_x(\alpha H2;\ \beta CO2)}{NO_X(\ pur\ NG)}$ at the exit of the combustion chamber is presented on figure 2 at various % H_2 content in the hythane. This figure reveals that the addition of hydrogen within naturel gas increases the concentrations of NOx. In fact, the addition of hydrogen reduces the dilution of the reactants by the products of combustion and reduces the residence time of the various products which consequently, increases the flame temperature and the thermal NOx formation. It can be seen from this figure that the diluted combustion of CO_2 decreases the NOx emissions, in effect the addition of CO_2 induces a decrease of flame temperature by reducing reactant concentration inside the reaction zone leading to a decreases the the NOx emissions.This result depicts a good agreement with the available data in the existing literature [8].

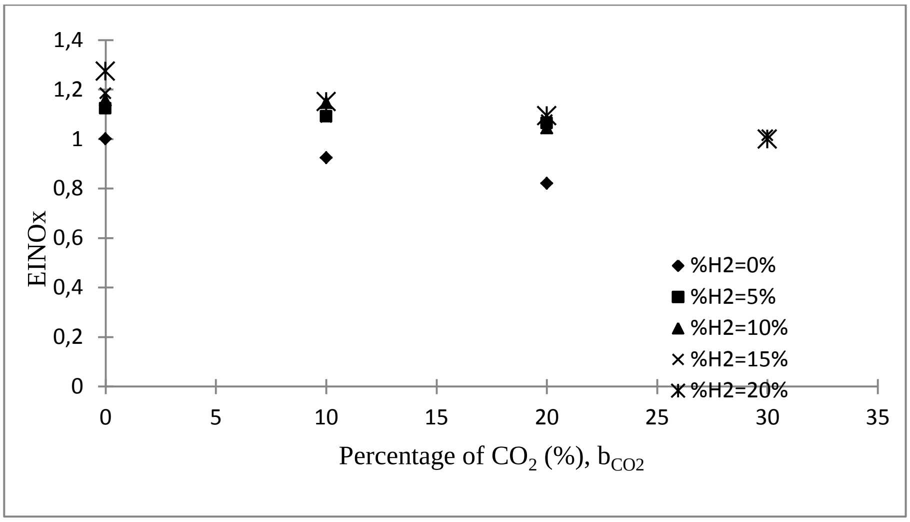

Fig.2: Nitrogen oxides emission according to hydrogen volume fraction and CO_2 dilution

4.2. Carbon monoxide emission:

Figure 3 illustrates the variation of absolute carbon monoxide emissions with the %CO_2 added at various % H_2 content in the fuel, at the exit of the combustion chamber, where EICO is defined by $\frac{CO(\alpha H2;\ \beta CO2)}{CO(\ pur\ NG)}$. From this figure, it can be seen that the hydrogen addition, for the same % CO_2, reduces the CO emissions, also the CO mole fraction increases consistently with the rise of CO_2 dilution for the same percentage of H_2. This is due to the fact that the CO_2 addition in a non-premixed methane/air flame lowered flame temperature by decreasing reactant concentration inside the reaction zone.

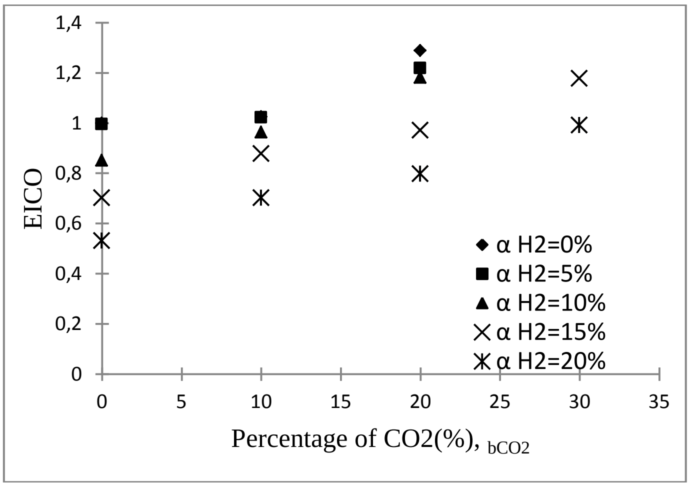

Fig.3: Carbon monoxide emission according to hydrogen volume fraction and CO_2 dilution

Conclusion

The effects of carbone dioxide dilution and hydrogen addition on the NO_x emissions and the CO emission in natural gas-hydrogen-carbon dioxide-air flames from a cylindrical burner have been experimentally studied. The measurements of NOx and CO concentrations are carried out at the exit of the combustion chamber using a water-cooled probe, NOx analyzer and CO analyzer.

The results showed that the diluted combustion of CO_2 decreases the flame temperature, the NOx formation particularly through thermal mechanism and increase CO emissions. Also, the addition of hydrogen increases the flame temperature, the thermal NOx formation and decrease CO emissions.

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