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Influence on the Energy Use by the Fuel Dilution with Combustion Products

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ABSTRACT

The radiation heat transfer is the predominant mechanism to the energy use in several industrial applications. The hot gases from combustion products and soot are the main participant media in radiation. Then, the use of the combustion products, premixed with fuel as reactant, favors this process. Thus, the reuse of the combustion products allows to increase the efficiency and to reduce the emissions. In this context, this work aims to assess the energy emission by radiation from the reaction of fuel diluted with combustion products. Also, the qualitative soot production were measured in the methane fuel diluted with combustion products in several proportions. The results contribute to understand the energy transmission from the combustion of diluted. This information is of fundamental interest in projects to design combustion systems, developments and prediction of suitable industrial systems, such as enhancing the predicting engineering tools. The continuity of this works intend to consider another fuels, different diluents and initial temperature of the reactants in order to analyses the real conditions of the combustion products regeneration.

Key-words: Combustion Technology, Propulsion Systems, Energy Use, Diluted Fuel.

INTRODUCTION

The interest of engineering in soot is due the heat transfer by radiation, which depends on the industrial applications has positive or negative influence. Soot particles increase and homogenizes heat transfer, instead the presence of particulate matter in diesel engines is harmful, Turns (2000). In gas turbines the presence of soot affects the blades life-time due to abrasion. The soot emission to the atmosphere causes the greenhouse effect and a significant deterioration in air quality. Consequently, induces respiratory diseases and also is associated with the cancer Caetano, et al. (2013).

Non-intrusive optical techniques based on laser are the preferred method to measure with accuracy, spatial and temporal resolution Hadef, et al. (2010). Over the past 20 years, laser-induced incandescence (LII) has proven in numerous studies to be a useful tool in soot volume fraction measurements, resolved in time and space for a wide range of applications, such as laminar and turbulent flames, combustion within the engine cylinders, and characterization of the engine exhaust gases, Caetano, et al. (2014). LII provides soot volume fraction results and performs real-time measurements, Vander Wal and Weiland (1994).

Soot formation in pure hydrocarbon fuels is the subject of several studies found in the literature Melton (1984), Santoro (1983), Vander Wal and Weiland (1994) Michelsen, et al. (2003); Hadef, et al. (2010); Schulz, et al. (2006); Caetano, et al. (2015). However, the inert gases diluting fuel is not well understood. The actual scenario required alternative energy sources use, which indicates the importance to study the fuel dilution effects. Thus, in this study, the formation of soot in laminar diffusion flames diluted with inert gas was evaluated. Different proportions of dilution of carbon dioxide and nitrogen were considered.

In the same context, the interest of engineering in radiation is due the heat transfer to the industrial energy use and safety. The heat exchanged by radiation in hydrocarbon diffusion flames is mainly due to spectral bands emission from water vapor and carbon dioxide and, also, to continuous spectral emission from soot particles Sivathanu and Gore (1993). The presence of soot increases substantially the heat transfer by radiation mechanism Turns (2000).

The combustion products are composed by a high CO_2 concentration, which emits and absorbs radiation affecting the heat transfer. Fuel dilution with this specie inhibits the soot formation Mishra and Kumar (2010), due the low flame temperature and less soot precursor concentration.

Radiation is important because transfer heat contactless with the material medium, which allows several industrial applications Turns (2000). For this reason, radiation emission is the focus of several studies aiming to investigate the use of the energy released by combustion. Therefore, it is possible to reduce the pollutions emission and to increase the energetic efficiency on several applications. An overview in aerospace research and industry has shown a fundamental importance in shuttle load gain, velocity, energy efficiency and, also, safety regarding human and equipment.

METHODOLOGY

The method applied to evaluate the thermal radiation emitted by flames consists in perform measurements of heat flux in different positions around the source using a sensor called radiometer, Hankinson and Lowesmith (2012).

Among the different studied methods, the simplest is the single point model, which considers the flame as one heat source located in the central flame axis at a medium flame height and 2.5 to 3 flame length far from the source Sivathanu and Gore (1993).

A radiometer was used to perform the thermal radiation flux measurements. A heat flux transduction based on the Schmidt-Boelter principle, brand Medtherm, model 64-0.520/ZeSeW-1C-150, ranging from 0 to 0.5 kW/cm^2, 3% of uncertainty and, a solid angle of 150º. The quantum efficiency of sensor is constant in the bandwidth between 0.5 to 20 μm. This feature allows to direct measure radiation from flames of different fuels and temperatures without require signal compensation.

The system used to measure soot volume fraction was the Soot Master, LaVision GmbH, which is designed to perform LII technique. The laser Nd:YAG, brand Quantel, model

Evergreen, has 200 mJ per pulse to 10 Hz repetition rate. Each pulse has 7.4 ns, wavelength of 532 nm and 5 mm of beam diameter. A light sheet has 100 mm of height and 500 µm of the waist thickness.
The CCD exposure time was set to 3,100 µs, which capture the image intensifier phosphorescent signal with delay set to 5 ns, 40 ns of gate and 50% of gain. The optical band-pass filter employed, positioned in front of the camera, is centered at 360 nm.
Flames configurations was performed with a constant flow input of natural gas (NG) and different increments whether CO_2 or N_2, as detailed in the Table 1.

Table 1. presents the cases configurations considered in this work.

case	**flow (liter/min)**			**dilution**
	NG	**CO_2**	**N_2**	**%**
A	0.5	0	0	0
B	0.5	0.056	0	10
C	0.5	0.125	0	20
D	0.5	0.214	0	30
E	0.5	0.333	0	40
F	0.5	0	0	50
G	0.5	0	0.056	10
H	0.5	0	0.125	20
I	0.5	0	0.214	30
J	0.5	0	0.333	40
K	0.5	0	0.5	50

RESULTS

Figure 1 presents the profiles in the flame region which maximum soot amount was observed from the images obtained applying LII technique in flames with both, carbon dioxide and nitrogen dilution.

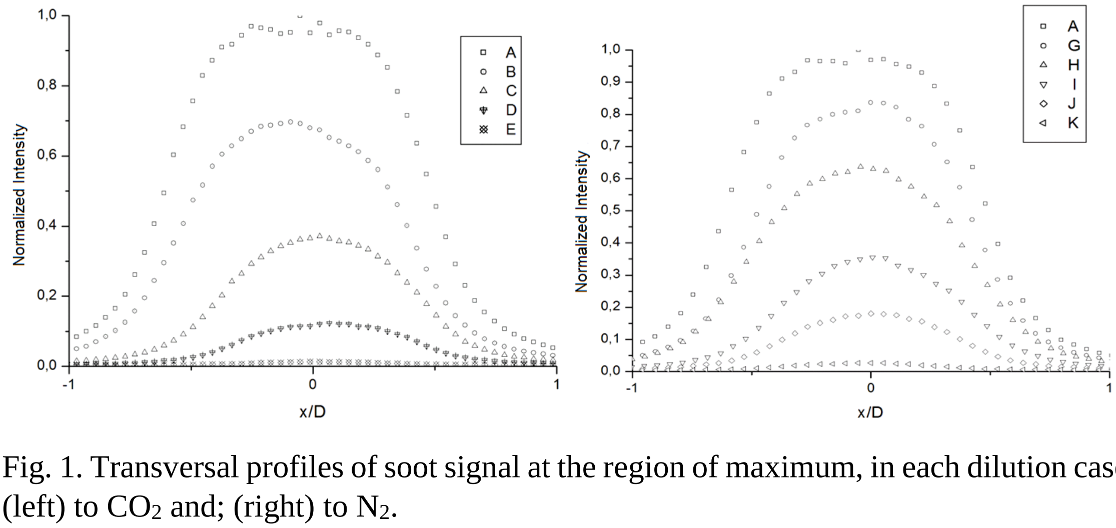

Fig. 1. Transversal profiles of soot signal at the region of maximum, in each dilution case, (left) to CO_2 and; (right) to N_2.

The reduction in soot formation as dilution increases is due the chemical effect given by the fuel concentration reduction in the reaction zone, producing low precursors Schulz 2006. Also, there are changes in the flame temperature, since soot formation depends on

the competition between fuel pyrolysis reactions, oxidation of soot precursors and oxidation of soot itself Glassman (1988). Both processes increases the reactions, more enhanced than pyrolysis reactions.
Pyrolysis and oxidation reactions takes place in the different flame region. Hence, low temperatures lead less precursors. Thus, the carbon dioxide dilution yields lower adiabatic temperatures than nitrogen dilution, such as observed in the results.
Figure 2a shows the normalized integral LII signal captured on the images for the whole flame, for each diluted case, for CO_2 and N_2. The Figure 2b presents the radiation fraction in function of dilution to both inert gases, CO_2 and N_2.

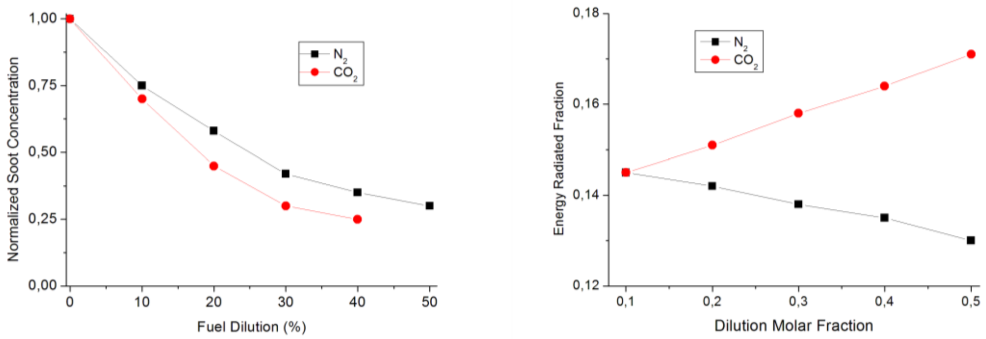

Fig. 2. (a) Normalized result of the LII signal integrated over the whole image, for the diluted cases. (b) Radiation fraction as function of dilution to both inert, CO_2 and N_2.

In the Figure 2a results two main effects was observed yielded by the dilution on soot production. First, is the precursor reduction and the second is the flame temperature reduction. The soot distribution behavior is similar to both, N_2 and CO_2. However, flames diluted with CO_2 shown smaller soot amounts than N_2.
The addition of CO_2 in the fuel shown an increase in the radiation fraction values, as seen in Figure 2b, even that it decreases the amount of soot produced. In the other hand, the increase in the N_2 dilution proportion causes systematically a decrease in the radiation fraction, due reduction in the flame temperature and the inhibition of soot formation, which is an important media to the radiation emission.

CONCLUSIONS

The results for soot production shown that the addition of nitrogen causes a reduction in the soot formation. Since the same dilution ratio is considered, the carbon dioxide is the most influent in the soot reduction, regarding the measuring technique limitations.
The radiant fraction is reduced with the progressive CO_2 dilution, which can be related with the inhibition of soot formation and the reduction of the flame temperature. Also, the dilution of the fuel with inert gases to those flames considered causes a flame length reduction.
The information provided in this work allows to analyze the typical characteristics of the combustions system in terms of project or adaptations for the fuel dilution. The parameters as soot presence, thermal radiation emitted to surrounds and flame shape contributes to knowledge in order to increase the energy use efficiency for cases in which fuel dilution are considered.
Future works intend to consider another fuels, inert dilutions and initial temperature of the reactants.

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