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STUDY OF THE EFFECT OF OXYGEN ENRICHED AIR ON THE FORMATION OF SOOT IN AN ACETYLENE DIFFUSION FLAME

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Abstract. This work evaluates the influence of the oxygen content on soot formation in acetylene diffusion flames, produced in a burner with parallel annular coaxial oxidizer flow. The results concern oxygen contents in the combustion air smaller than thirty percent, which usually do not require significant existent equipment changes. The methodology used for calculation of the soot concentration was the non intrusive technique based on laser light extinction. The results suggest that the concurrent manipulation of the oxygen content and of the oxidizer velocity can provide a control tool for soot formation.
Keywords: *Soot Formation, Acetylene Diffusion Flame, Oxygen Air Enrichment*

1. INTRODUCTION

Soot formation in industrial combustion systems constitutes topic of engineering interest, because the presence of soot in the flame increases the heat transfer from the combustion gases by thermal radiation, and when emitted in the atmosphere constitutes an environmental problem, besides increasing the need for burner maintenance. The phenomenon of soot formation still is not fully explained, a consequence of the fact that the formation process isn't slow enough to allow the precise observation of each step. The demand for new scientific knowledge concerning soot, including the use of chemical additives to control its formation, has been attended by works that, in their majority, are performed with elementary flames, as in the present study. Oxygen, one of the possible soot oxidizers, has been considered as an additive. The enrichment of combustion air with oxygen can improve the combustion process, as mentioned by Baukal [1998], by determining improved flame characteristics - larger inflammability limit, better ignition, stability and shape control; smaller combustion gas volumes; increased productivity and thermal efficiency: larger efficiency of the heat transfer processes; improved product quality; fuel consumption reduction, raw material costs reduction, reduced costs of new equipments and, possibly, production increase in existing equipments. Atmospheric air has about 21% of oxygen in volume. Low levels of oxygen enrichment of the combustion air, which correspond to an O_2 index in the combustion air below 30%, are usually used in retrofit applications in that only small modifications are necessary in the existent equipment.

The addition of oxygen in diffusion flames can be carried out by direct addition to the fuel or to the combustion air in a burner with parallel annular oxidizer flow.

The direct addition of oxygen to a methane diffusion flame was studied by Saito et al. (1986) and Gülder (1995). Wey et al. (1984), Hura and Glassman (1987), Du et al. (1990), Leung and Lindstedt (1991), and Gülder (1995) studied the addition to propane and butane diffusion flames. Hura and Glassman (1988), Du et al. (1990), Leung and Lindstedt (1991) and Hwang et al. (1998) studied the addition of oxygen to ethane diffusion flames. Kent and Basin (1984) studied the addition to acetylene diffusion flames.

In relation to addition of oxygen to the combustion air in a burner with a parallel annular oxidizer flow the literature is constituted by the works of Glassman and Yaccarino (1980), Lee et al. (2000) and Zelepouga et al. (2000).

Glassman and Yaccarino (1980) studied the influence of the O_2 concentration in ethylene flames. The O_2 index was varied by the authors between 9 and 50%. It was observed that soot formation went to a minimum around 24%. This tendency was explained by the competition between the fuel pyrolysis and soot oxidation in the domain of the process.

Lee et al. (2000) studied the influence of O_2 enrichment in methane diffusion flames for conditions of 50 and 100% of O_2. The authors found a reduction of soot production in the two enrichment conditions, with a larger reduction for the later condition.

Zelepouga et al. (2000) also examined the influence of O_2 enrichment on the air side of methane laminar diffusion flames, for 35, 50 and 100% of O_2. This time, the evaluation parameter was the integrated radial soot concentration. The authors observed a reduction in soot formation in all situations, and proposed that soot concentration was smaller for flames with the larger O_2 index, due to smaller flame lengths and, in consequence, smaller times of residence available for soot particle growth.

The flame studied in the present work was generated in a vertical axis burner in which the discharge of acetylene was surrounded by a coaxial annular flow of oxygen enriched air. The applied enrichment levels were 23 and 25%, which, when used in retrofit applications, require only small modifications in the existent equipment. The purpose of the work was to explore the effect of the oxygen content and the combustion air velocity on the soot concentration along the height of an acetylene diffusion flame

2. EXPERIMENTAL APPARATUS AND METHODS

The experimental setup is shown in Fig.1. The flame was generated in burner QM1 in which acetylene flew up through a vertical tube, and air or enriched air flew through the annular region between this tube and a larger diameter concentric tube.. The diffusion air and oxygen were premixed in PM1, before being fed to the burner QM1, whose dimensions are shown in Fig. 2. Gas flow rates were controlled by valves V1, V2, V3 and metered by rotameters R1, R2 and R3.

Soot concentration was measured along the flame height by means of the laser light extinction technique. The burner was mounted on a step-motor driven vertical translation table, which allowed the beam coming from laser L1 to reach the flame at any desired level. The laser L1 was of He-Ne, with a wavelength of 632.8 nm. Since the power output from

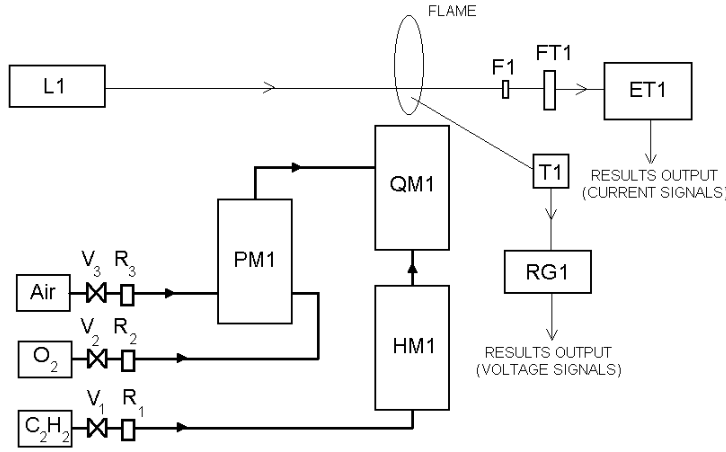


Fig.1 - Experimental Setup

the laser was only about 1mW, background radiation was blocked from the flame by a narrow band pass interference filter F1, at the laser wavelength. The light was transformed in a electrical current signal by the photodiode FT1, and registered by electrometer ET1.

Flame temperatures were measured by an uncoated type S thermocouple T1 (Pt-Pt/10%Rh) along the central axis of the flame, and the signals were registered by the temperature meter RG1. The thermocouple tip was cleaned out before every temperature reading. The obtained results were not corrected for radiative and convective losses, considering the uncertainty in evaluating the effect of soot deposition on the thermocouple surface.

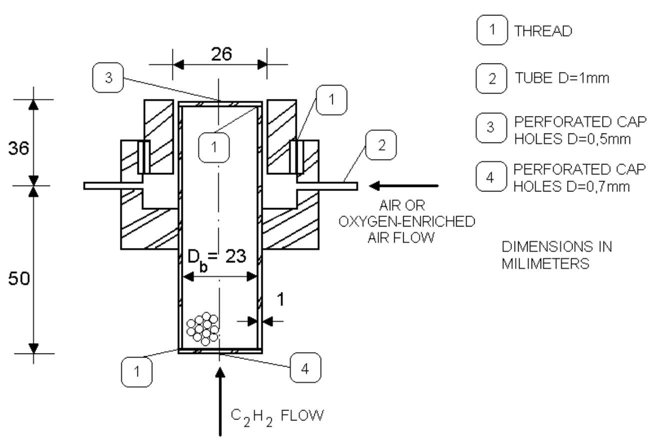


Fig. 2 - Burner QM1

Soot volume fraction, C (ppm), was calculated from the laser light extinction data, using the Rayleigh limit of the Mie theory, so that:

$$C = \frac{-\lambda}{6\pi \operatorname{Im}\{\frac{(m^2-1)}{(m^2+2)}\}} K_{ext} \qquad (1)$$

where

$$K_{ext} = \frac{1}{L}\ln\left(\frac{I}{I_o}\right) \qquad (2)$$

λ is the laser wavelength, L the optical path length, I_0 and I the laser beam intensity before and after traversing the flame, and m is the refractive index, adopted as m = 1.90-0.55i, according to Lee and Tien (1981).

To examine the effect of the oxygen content on the combustion air, tests were performed comparing experiments with 23 and 25% of oxygen content to experiments with plain air, stagnant or flowing. The air velocities, Var, were 0.10, 0.15, 0.85 and 1.39 m/s, and the acethylene velocities, Veg, were 0.22 and 0.36 m/s, referred to 20°C and atmospheric pressure. The burner power was 0.72 and 1.16 kW. Table 1 summarizes the combination of fluid velocities in the tests.

Table 1 – Var/Veg in the Experiments

Veg	Var [m/s]						Power
[m/s]	0	0.10	0.15	Veg	0.85	1.39	[kW]
0.22	0	0.45		1	3.86		0.72
0.36	0		0.42	1		3..86	1.16

3. RESULTS AND DISCUSSION

Figures 3 and 4 present the soot concentration along the flame height for experiments where Var < Veg and Var > Veg, respectively. The position in the flame is given in terms of an ordinate made dimensionless by the ratio with the visible length of the flame, a procedure which gives a correspondence between the flames regions.

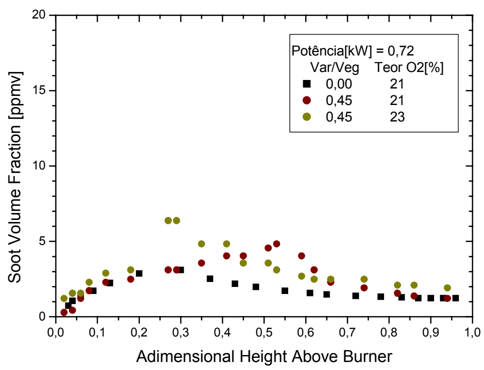
The effect of the oxygen content in the enriched combustion air was determined by comparison of tests with the same burner power and the same Var /Veg.

3.1 Var < Veg

When Var < Veg the combustion air is set in motion by the gas jet, that exerts the control of the contact between the fluids. The mixture improves as the relative velocity increases, so that the situation with the least fuel-oxidant mixture is experienced when Var=Veg.

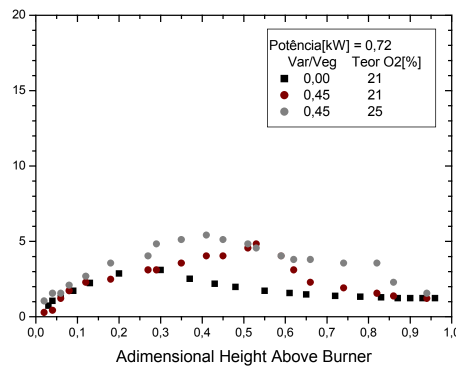
Figure 3 shows the results which were obtained for Var /Veg$\cong$0.45, with the burner power equals to 0.72kW in figures a. and b., and to 1.16 kW in figures c. and d.

It can be observed that the O_2 enrichment caused an increase in the concentration of soot along the flame, as compared to the reference test, assumed as the test in which air was not enriched and stagnant, as well as to the test in which the air was enriched with oxygen and had the same gas velocity. The O_2 effect can be better observed in the 25% condition. It was also noticed that air motion alone was sufficient to increase soot concentration, in comparison with the reference case, explained by the decrease of air entrainment in the flame seen in this condition.



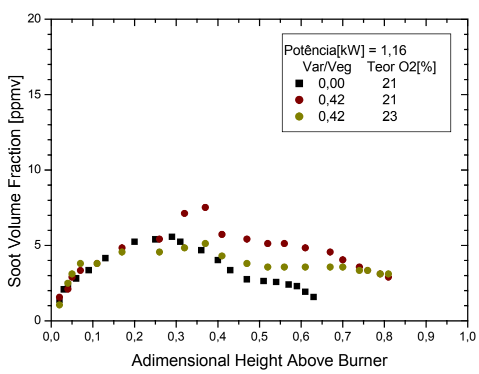
a. Burner Power = 0.72 kW;

O_2 Content = 21 e 23%.



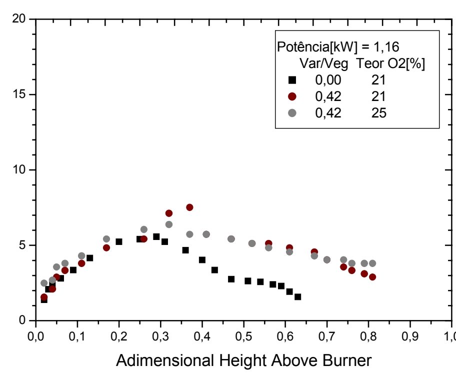
b. Burner Power = 0.72 kW;

O_2 Content = 21 e 25%.



c. Burner Power = 1.16 kW;

O_2 Content = 21 e 23%.



d. Burner Power = 1.16 kW;

O_2 Content = 21 e 25%

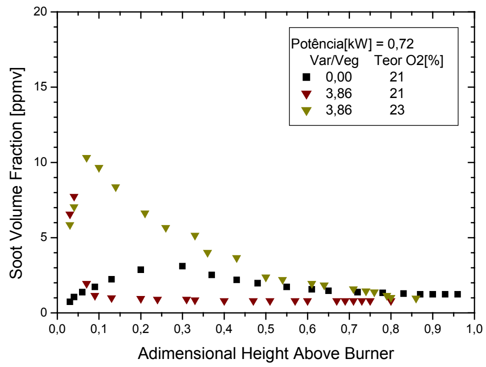
Figure 3 – Soot Concentration Along the Flame Height

V_{ar}/V_{eg} = 0 and 0.45.

As the burner power was increased to 1.16 kW, there was an increase in soot concentration for the 23% enrichment condition, as compared to the reference condition, but this rise was not larger than for plain air flowing with the same velocity. One possible explanation for that is the competition between the zones of formation and oxidation of soot, which would be diversely affected by O_2 enrichment.

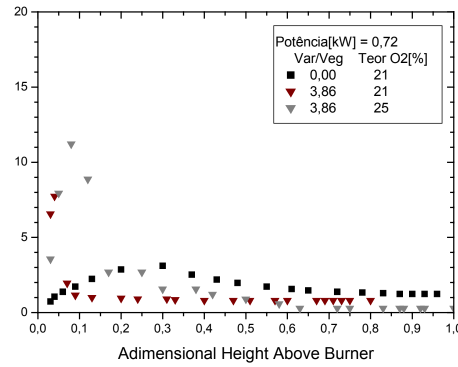
3.2 Var > Veg

Figure 4 shows the results which were obtained for Var /Veg=3.86, with burner power equals to 0.72kW in figures a. and b., and 1.16 kW in figures c. and d.



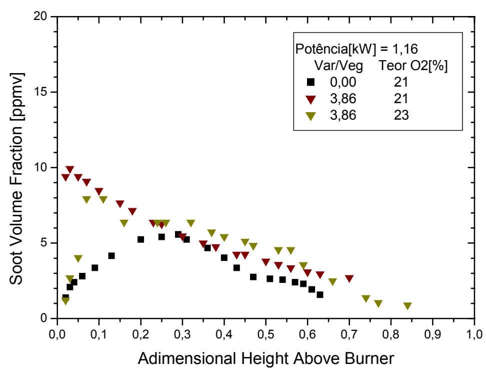
a. Burner Power = 0.72 kW;

O_2 Content = 21 e 23%.



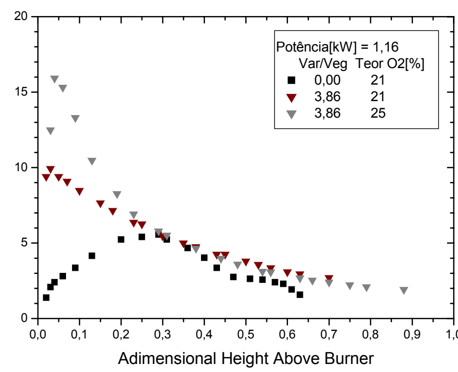
b. Burner Power = 0.72 kW;

O_2 Content = 21 e 25%.



c. Burner Power = 1.16 kW;

O_2 Content = 21 and 23 %.



d. Burner Power = 1.16 kW;

O_2 Content = 21and 25%

Figure 4 – Soot Concentration Along the Flame Height

V_{ar}/V_{eg} = 0 and 3.86

It can be observed that at this air velocity soot concentration at the flame basis increased intensively in all tests where air flow was imposed, that is, for both plain and enriched air with oxygen contents of 23 and 25 %. The soot concentration level was higher when air was enriched, and increased with the oxygen content. This would be due to the strong fuel-air mixing, which increases the pyrolysis rate and, as a consequence, soot formation. The soot just formed in this process would, in the sequence, be reduced by oxidation, which was also intensified by oxygen enrichment of the combustion air.

As the burner power increased there was an increase in soot formation, which can be explained by the higher temperatures achieved in the flame.

4. CONCLUSIONS

The influence of the oxygen content on soot formation in acetylene diffusion flames, produced in a burner with parallel annular coaxial oxidizer flow, was explored. The applied enrichment levels were 23 and 25%, which, when used in retrofit applications, require only small modifications in the existent equipment.

The results suggest that the simultaneous variation of the oxygen content and of the oxidizer velocity can provide a control tool for soot formation.

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