EXERGY ANALYSIS OF NATURAL GAS CONFINED FLAMES WITH OEC

CONFERENCE PAPER · NOVEMBER 2014

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Abstract. *The concept of environmental efficiency in equipments is increasingly in tariff with the unfolding of global warming, and, among the industrial equipments, the burners have a major impact in this discussion because it is an equipment of industrial combustion. Demand for environmentally more efficient burners, with the reduction of emissions is essential for the proper use of fossil fuels during the transition between this energy sources for alternatives energy, which can last more than fifty years. This study evaluates exergetic analysis of oxygen enhanced combustion in natural gas confined flames. The literature shows that works with OEC technique – technique that has important points for improving the thermal efficiency of combustion – cause under certain conditions the increase of soot formation. The soot as an important participant in the radiant heat transfer, it can, with its interaction with the OEC, bringing the increase in thermal efficiency of burners, implementing the heat transfer from the flame for heating areas, thereby reducing the consumption fuel, the temperature of flame. The exergetic analysis will confirmed the improving the thermal efficiency with OEC in combustion systems with natural gas.*

Keywords: *OEC, natural gas, combustion, exergetic analysis, burners.*

1. INTRODUCTION

Oxygen enhanced combustion (OEC), mentioned by Baukal (1998), can improve the combustion process by producing improved flame characteristics (larger inflammability limit, better ignition, stability and shape control); smaller combustion gas volumes; increased productivity and thermal efficiency (larger heat transfer process efficiency, improved product quality; fuel consumption reduction, raw material costs reduction, reduced costs of new equipment and possibly production increase in existing equipment).

Atmospheric air contains about 21% of oxygen in volume. Low levels of enrichment of the combustion air with oxygen, i.e. an O_2 index below 30%, are usually used in retrofit applications in which only small modifications to the existing equipment are necessary.

The literature shows that works with OEC technique – technique that has important points for improving the thermal efficiency of combustion – cause under certain conditions the increase of soot formation. The soot as an important participant in the radiant heat transfer, it can, with its interaction with the OEC, bringing the increase in thermal efficiency of burners, implementing the heat transfer from the flame for heating areas, thereby reducing the consumption fuel, the temperature of flame (Santos *et al.* (2011), (2012)).

Data about soot, including the use of chemical additives to control its formation, has been obtained mostly from studies performed with elementary flames as in the present work. These flames are usually defined as either premixed, partially premixed, or non-premixed (diffusion) flames.

In a diffusion flame the reactants are initially separated, and reaction occurs only at the interface between the fuel and the oxidizer where both, mixing and reaction, take place. 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 an annular, parallel or counterflow oxidizer.

The direct addition of oxygen to a methane diffusion flame has been studied by Saito et al. (1986) and Gülder (1995). Wey et al. (1994), Hura and Glassman (1988), 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.

Maidana *et al.* (2010) studied the influence of OEC in the energetic efficiency combustion of gas power cycle. Lambert *et al.* (1997) studied the efficiency of second law to influence of OEC in the steam methane reforming. But a few works explored the OEC with exergetic analysis.

The objective of the present work is to explore the effect of the oxygen content in the oxidizer of the combustion on the thermal efficiency. The exergetic analysis was used to confirm the thermal efficiency with OEC in natural gas confined flames. The applied enrichment levels were 23 and 25% O_2 and they were used in retrofit applications where only small modifications in the existing equipment are required.

2. ANALYSED SYSTEM AND METHODOLOGY

The system setup analyzed is shown in Fig. l. The flame was generated in a horizontal cylindrical combustion chamber, which consisted of burner with two concentric tubes: a 5mm i.d. central tube, and a 100mm i.d. external tube, and a chamber 1.35m in length. Natural gas flowed up through the internal tube, while air, or enriched air, flowed through the annular region between this tube and the larger diameter concentric tube. Diffusion air and oxygen were premixed before being fed into the combustion chamber.

To examine the effect of the oxygen content of the combustion air, simulation with EES (engineering equation solver) were performed comparing volumetric index 23 and 25% of O_2 in the oxidant with plain air (21% O_2). In the simulation the equivalence ratios (φ) 1.3, 1.0 and 1.0 were analyzed. The natural gas flow was $0.0003 m^3/s$ (18 l/min). The burner power was 9.76kW.

Figure 1: System Setup View of Combustion Chamber Analyzed.

The methodology of the implemented analyze was the evaluation using the concept of exergy as basis; from this methodology were evaluated the exergetic efficiencies (the second law) of the combustion processes with OEC and plain air.

The free energy that is available (exergy), is calculated from the water taxes and from the exhaustion gases, and it was found from the concept of the specific exergy (ex), spreading in many literatures, like Wylen et al. (2003), is presenting as:

$$ex = (h - h_0) - T_0 (s - s_0) \tag{1}$$

The symbol "h" is the specific entalphy and the "s" is the specific entrophy, and "ho" and "so" are the values of the specific entalphy and entropy to the references of the conditions.

The variance of enthalpy, entropy and the heat specific of the exhaustion gases is given by the following correlations:

$$\Delta h = \int c_P \Delta T, \Delta s = \int \frac{c_P}{T} dT e c_P = \sum_j x_i c_{pi} \tag{2}$$

$c_{pi} = A_i + B_i T + C_i T^2$ (Calen, 1960) and represent the calorific capacity of the i compound, presenting in the exhaustion gases, calculated from the composition of the natural gas and the mixture of diesel/biodiesel, masses of air and fuel, considering the proportion of the elements in a composition combustion.

Yet, the exergies of the used fuels were determined from the formulation, which was presented by Kotas (1985) referencing Szargut and Styrylska (1964), which determine a factor φ to calculate the associated exergy to the fuel, from the elementary composition in mass of the fuel, and from the calorific inferior power (PCI). This factor, to liquid fuels, is given in the following way:

$$= 1.0401 + 0.1728 \frac{h}{c} + 0.0432 \frac{o}{c} + 0.2169 \frac{s}{c} \left(1 - 2.0628 \frac{h}{c} \right) \tag{3}$$

The "h", "c", "o" and "s" are percentages in mass of the elementary analyze of the fuel. To the natural gas, this value is tabled and presents 1.04 +/- 0.5% (Kotas, 1985). The exergies of the fuels will be found from the multiplication of this factor with the PCI of each analyzed fuel as:

$$ex_{Comb.} = \phi * PCI_{Comb.} \tag{4}$$

The pressure and ambient temperature conditions of reference, which were established to the work, were 101.30 kPa and 25 ºC.

The thermal efficiency from second law for the combustion processes, were based on presented concepts by Kotas (2005). The formulation to the efficiency calculation is given in the Equation (5) where η is the indirect thermal efficiency of combustion process from second law:

$$\eta = 1 - \left(\frac{Exergy_{products}}{m_{fuel} * ex_{Comb.}}\right) \tag{5}$$

3. RESULTS AND DISCUSSION

Through experiments with volume fractions of 21, 23 and 25% of gaseous oxygen in the oxidizer and equivalence ratios of 0.1, 1.0 and 1.3 , the flue gas temerature results shown in Table 1 were reached. After applying the methodology described in Item 2 of this paper to the data exhibited in Table 1, energetic and exergetic efficiency data, also shown in Table 1, were found.

Table 1: Energetic and exergetic efficiency.

$\%_V O_2$	RE	T(K)	eff_{en}	eff_{ex}
21	0.7	950	60%	56%
	1	770	79%	75%
	1.3	700	86%	81%
23	0.7	730	76%	71%
	1	700	84%	79%
	1.3	470	95%	90%
25	0.7	740	77%	72%
	1	800	81%	76%
	1.3	780	85%	81%

Figure 2 exposes, graphically, the flue gas temperatures found for different percentages of oxygen as a function of equivalence ratio.

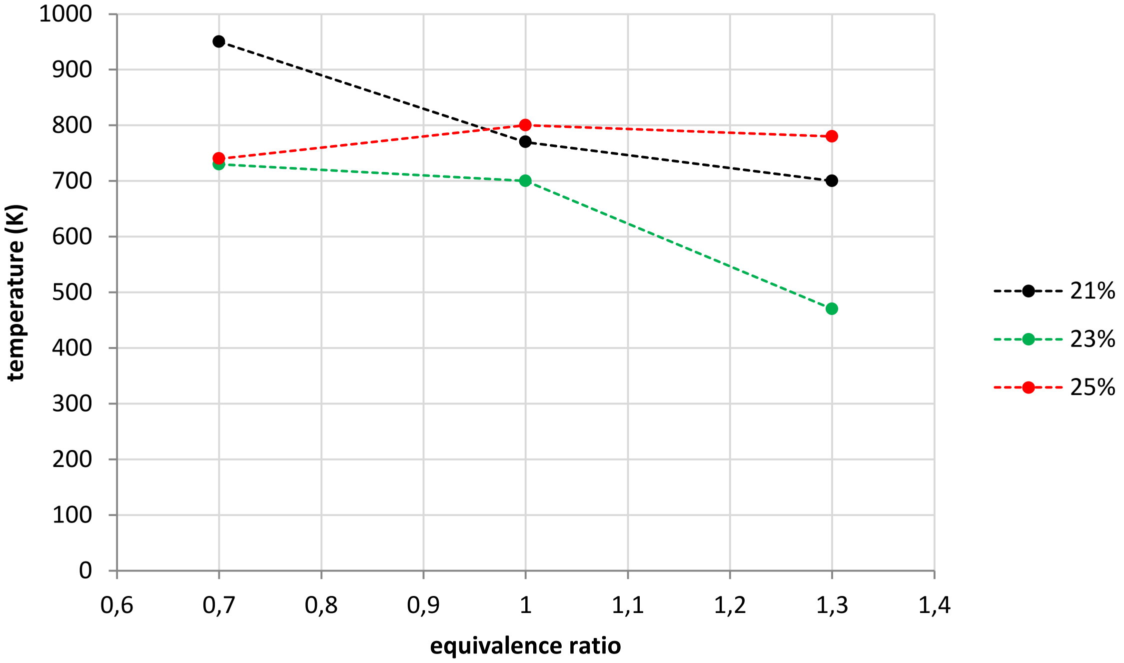

Figure 2: Flue gas temperature as a function of equivalence ratio.

Figures 3 and 4 represent graphically energetic and exergetic efficiency, respectively, as a function of the equivalence ratio.

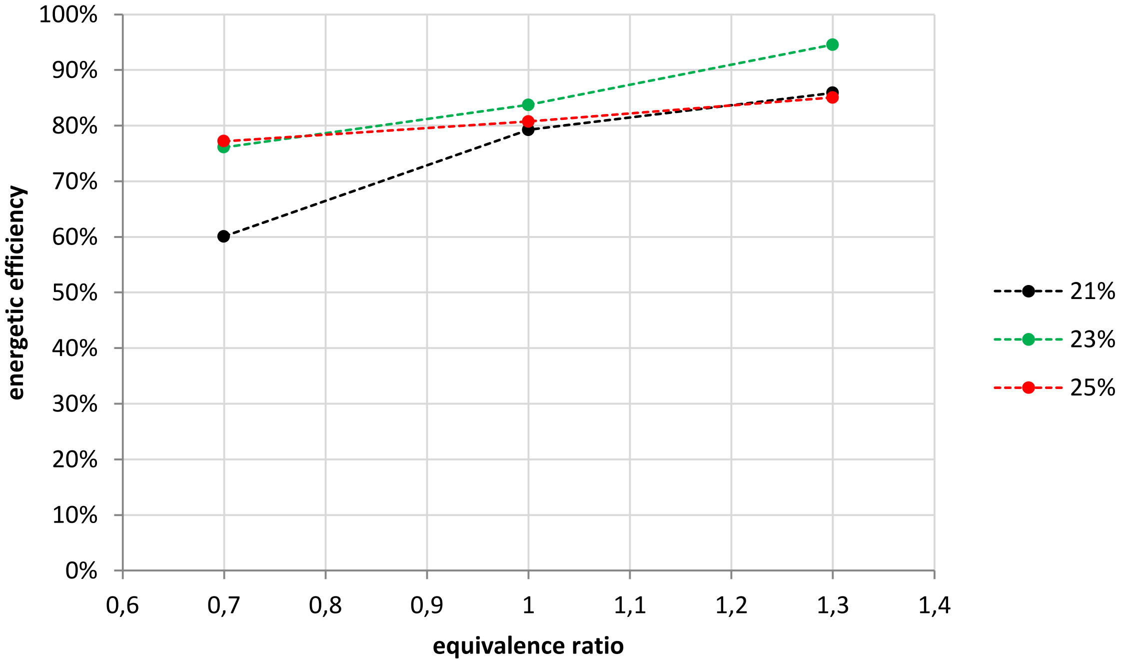

Figure 3: Energetic Efficiency as a function of the the equivalence ratio.

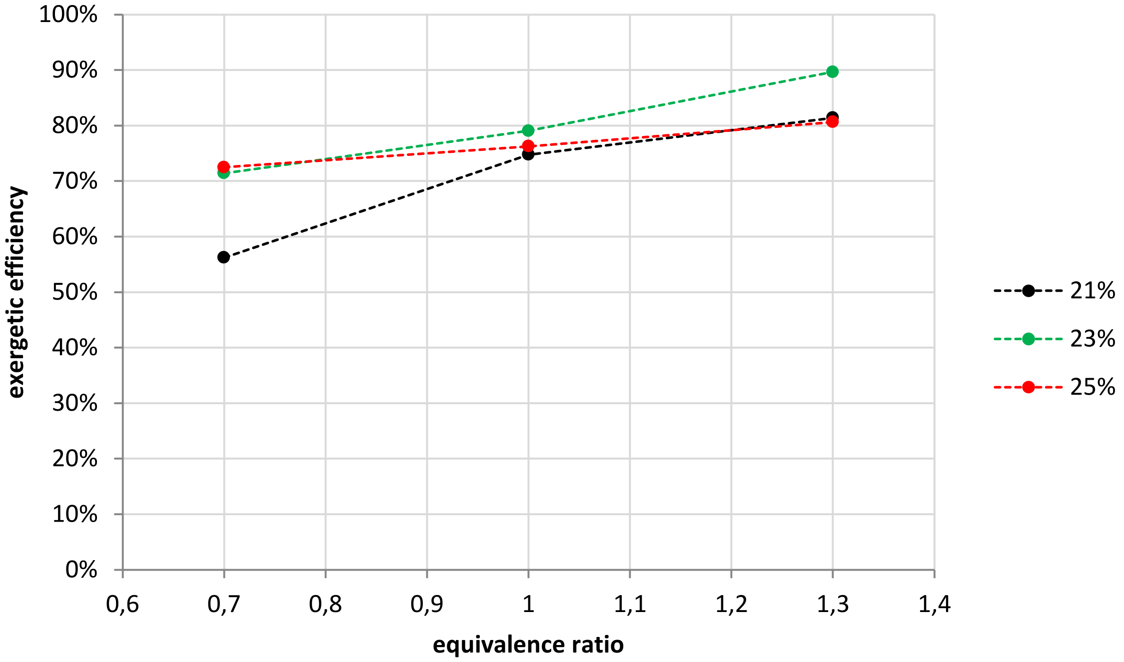

Figura 4: Exergetic Efficiency as a function of the equivalence ratio.

It is noted by observing the figures 3 and 4 that there is a close link between energetic efficiency and exergetic efficiency. This link denoted the major efficiency of radiation heat transfer in the chamber with OEC, because the available energy was used to heat transfer in the chamber and implemented the exergetic efficiencies. This fact encourages the development of the graph shown in Figure 5, where the exergetic efficiency is plotted as a function of energetic efficiency. The graph in Figure 4 encompasses all data obtained with all equivalence ratios and all the volume fraction of oxygen in the oxidizer.

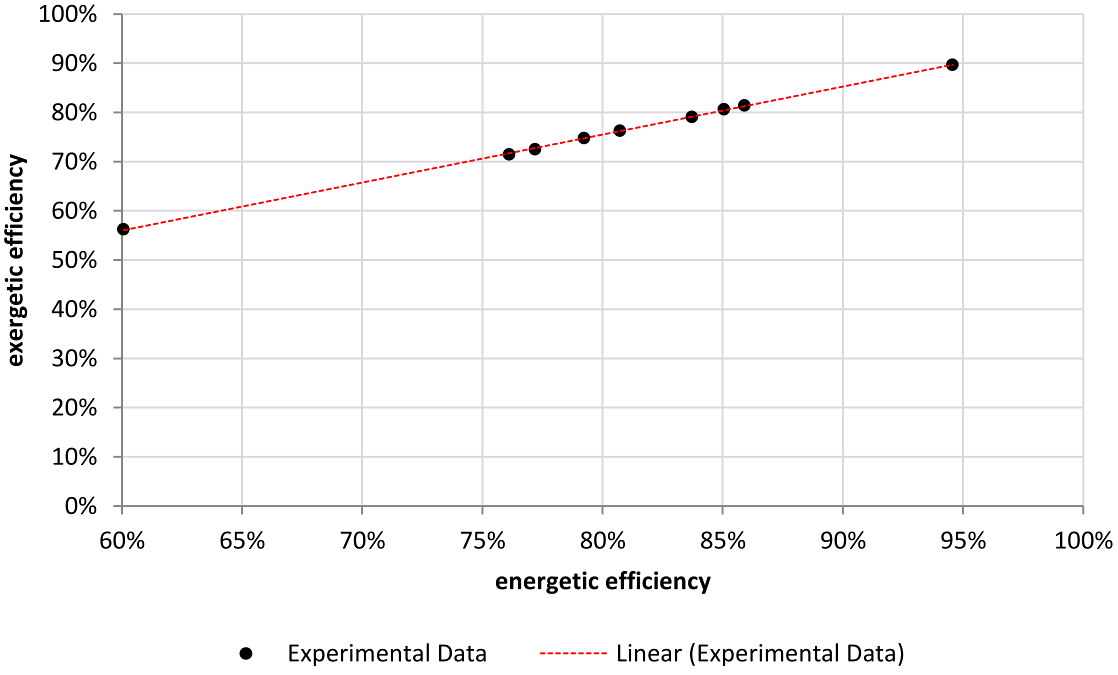

Figure 5: Exergetic efficiency as a function of energetic efficiency.

A linear fit of the exergetic efficiency data as a function of the energetic efficiency data can be made with a correlation coefficient R² of 0.9996. This correlation coefficient value of the, close to unity, allow the efficiencies found from the methodology and the data collected to be analyze the accurately using equation (6)

$$eff_{exergy} = 0.09754 . eff_{energy} - 0,0256 \quad (6)$$

Thus, the exergetic efficiency has always a lower value then the energetic efficiency one, fact that is consistent with the concept of exergy and its application.

Additional experimental tests will be performed to confirm the results already found and also expand the ranges of equivalence ratio and oxygen enrichment studied.

4. Conclusions

This work studied the exergetic analysis of natural gas flames with OEC using. The enrichment levels of study were 2 and 4%.

The results of work noted that there is a close link between energetic efficiency and exergetic efficiency. This link denoted the major efficiencies of radiation heat transfer in the chamber with OEC.

5. Acknowledgements

The authors are grateful for the financial support of the SENAI National Department – Brazil and the SENAI CIMATEC – Salvador – Bahia – Brazil.

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