



24th COBEM - 2017



24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-0428

INFLUENCE OF CORRELATION BETWEEN OEC AND ACOUSTIC EXCITATION IN NATURAL GAS FLAMES

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Abstract. *The use of combustion in industrial and human activities is of paramount importance for economic and social development. Even with the promotion of energy alternatives to reduce the use of combustion, this will be a mechanism for the generation of energy still widely used, either by the use of natural gas as a less polluting fuel, but also by the use of synthesis gases of biomass gasification. However, combustion reactions are the main sources of emission of atmospheric pollutants, such as CO, NO_x, volatile organic compounds and particulate matter. In view of this reality, it is necessary to study new techniques as well as the correlation between them in order to bring greater sustainability to combustion. The objective of the work is to correlate techniques such as oxygen-enhanced combustion (OEC) and the acoustic excitation of flames, forced by an external source, evaluating the effect of the use of these coupled techniques on the atmospheric emissions and thermal efficiency of the combustion in diffused and confined flames of natural gas. For this, an experimental prototype was developed with systems of acoustic performance and enrichment of the oxidant with oxygen. In the work is also presented experimental planning to identify the operational condition that optimizes together the emission levels of pollutants as well as the temperature of the exhaust gases in the flames studied. The results showed that the optimum operating point of the experimental device used is the simultaneous use of the two combustion techniques, which indicates the viability of the coupling between them. An increase in the stability of the flame acoustically excited with the use of OEC was also observed.*

Keywords: *OEC, pulsed combustion, acoustic excitation, natural gas flames.*

1. INTRODUCTION

Population growth in recent decades has led to extensive use of fossil fuel combustion, which in turn causes damage to the global environment; the main source of air pollution is emissions from all types of combustion systems. Carbon monoxide (CO) and nitrogen oxides (NO_x) are produced by burning fossil fuels and prove to be the causes of global warming and climate change. To reduce such damage to the environment, most developed countries have curtailed emissions regulations, which also reinforce studies on clean fuel use and techniques to increase process efficiency.

Energy efficiency is one of the fundamental points for the reduction of greenhouse gases emitted from industrial combustion processes. Industrial burners are therefore one of the main equipment that must have their thermal efficiency increased in order to reduce fuel consumption, as well as reduce the emission of greenhouse gases and pollutants. Numerous techniques are used for this purpose, such as staged firing, burners with swirling air, gas recirculation, fluidized bed combustion etc., however, the energy efficiency achieved is not always sufficient to reduce the consumption of fuels required for reality current.

There are no records of work that couple the acoustic excitation of flames and its influence associated with the combustion of gases coupled to the use of OEC. The improved improvement of the use of oxygen enrichment in the combustion, as well as the beneficial effects of the combustion generated with the acoustics in reducing the emission allow to infer that the correlation of these methodologies can bring benefits to the combustion of gaseous fuels.

It was designed and manufactured a burner with acoustic excitation device and oxygen enrichment to carry out the experimental analysis, which was performed using the DOE - Design of Experiments methodology, to determine the relationship between the factors that affect the combustion process of natural gas. To support the experimental analysis, the MINITAB® software was used.

The characteristics of diffusion flames under acoustic excitation have been widely studied in the combustion community. It is known that the range of acoustic frequencies and amplitudes can affect the dynamics of the flame. Some conditions of forced acoustic frequencies may induce unstable flame behaviour. In a closed combustion chamber, this instability can be increased due to the coupling between the heat release velocity and the acoustic pressure (Chao, *et al.*, 1992).

However, according to Toong (1965) at some excitation frequencies, forced acoustic excitation can be used to control combustion and improve thermal efficiency and pollutant emissions.

Demare and Baillot (2004), Kim, *et al.* (2009), Chao, *et al.* (1996), Saito, *et al.* (1998), Lovett and Turns (1993) studied the effects of acoustic excitation of flames, whether in energetic conditions, chemical or environmental kinetics.

The present work had the objective of evaluating experimentally the effects of the simultaneous use of OEC techniques and forced acoustic excitation in diffusive and confined natural gas flames, especially in the emission of pollutants such as carbon monoxide and nitrogen oxide and in the temperature of the gases of Exhaustion of the burn. For this, an experiment was carried out with three input variables: sound frequency, enrichment level and equivalence ratio, each being varied in three different levels and measuring the response for all possible combinations of these variables. The main goal was to obtain optimized operating conditions, where low emissions of partial combustion products such as CO were obtained, together with the reduction of NO_x emissions and also reduction in exhaust gas temperatures, indicating a better energy efficiency of the system.

2. EXPERIMENTAL PROCEDURE

In order to carry out the experiment, three controlled input factors will be considered: sound frequency, degree of oxidant enrichment, and air / fuel equivalence factor. Since "sound frequency" is a specific characteristic of the combustion technique excited with sound waves, the "oxidizer enrichment degree" is a characteristic factor of the oxygen enriched combustion technique (OEC) and the "equivalence ratio" is a Variable common in the study of the combustion phenomenon that gives a reference of the excess of air involved in the burning. The following factors will be considered fixed: those related to the equipment, chemical composition of the fuel, temperature of the gases inlet and batches of raw material. The variables to be analysed are: temperature, CO concentration and NO_x concentration of the exhaust gases.

In order to define the levels of the controllable factor "Enrichment Level or Degree or percentage of O₂ in the mixture", it was considered as maximum level 30% of O₂ in the mixture, which is the highest percentage of enrichment considered at the level of low enrichment in Baukal, (1998), for low levels of enrichment, it is not necessary to make major changes in the equipment for the application of the OEC technique, consequently as a lower level of enrichment the condition of zero enrichment or 21% Atmospheric, and as an intermediate level the condition of 25% of O₂ in the oxidant mixture was considered.

In order to define the levels of the Equivalence Ratio, the stoichiometric condition was considered as intermediate level, and for the lower and higher levels, the conditions of poor combustion and rich combustion were adopted. Evaluate the behaviour in the three basic combustion conditions.

Figure 1 show the experimental setup. The gas flow is 20.2 L/min and the regime of operation is transition for turbulence. The frequencies are 0 (no excitation), 160 Hz and 220Hz, and the equivalence ratio tested were 0.7, 1, 1.3, and the oxygen index in oxidant were 21, 23 and 25%. The experimental setup was inspired by the combustion device developed in the work of Ferreira, (2001).



Figure 1. Experimental Setup

3. RESULTS AND DISCUSSION

Tables 1, 2 and 3 shows the results of CO, NOx and exhaust gases temperature.

Table 1. Results of CO (ppm)

Frequency (Hz)	Equivalence Ratio								
	0.7			1.0			1.3		
	Oxygen Index								
	21	25	30	21	25	30	21	25	30
0	2,00	20,00	5,00	4,00	11,00	17,00	15,00	5,00	2,00
160	0,00	15,00	9,00	80,00	14,00	25,00	0,00	6,00	7,00
220	0,00	0,00	9,00	35,00	5,00	9,00	0,00	1,00	15,00

Table 2. Results of NOx (ppm)

Frequency (Hz)	Equivalence Ratio								
	0.7			1.0			1.3		
	Oxygen Index								
	21	25	30	21	25	30	21	25	30
0	58,00	63,00	130,00	130,00	59,00	63,00	61,00	59,00	59,00
160	101,00	60,00	67,00	67,00	37,00	66,00	102,00	61,00	73,00
220	126,00	75,00	173,00	173,00	69,00	64,00	56,00	61,00	57,00

Table 3. Results of Exhaust Gases Temperature (°C)

Frequency (Hz)	Equivalence Ratio								
	0.7			1.0			1.3		
	Oxygen Index								
	21	25	30	21	25	30	21	25	30
0	233,00	224,00	231,00	169,00	184,00	212,00	209,00	188,00	221,00
160	180,00	243,00	202,00	225,00	205,00	212,00	208,00	205,00	211,00
220	174,00	194,00	206,00	206,00	236,00	219,00	195,00	205,00	208,00

Figure 2 shows the results for CO and NOx emissions in the equivalence ratio of stoichiometry (as reference), with no excitation frequency and higher excitation frequency (220Hz). There is a small trend of CO reduction and maintenance of the NOx emission levels with an excitation relative to the non-excited flame. These characteristics are similar to those found in the other equivalence ratios when submitted to OEC.

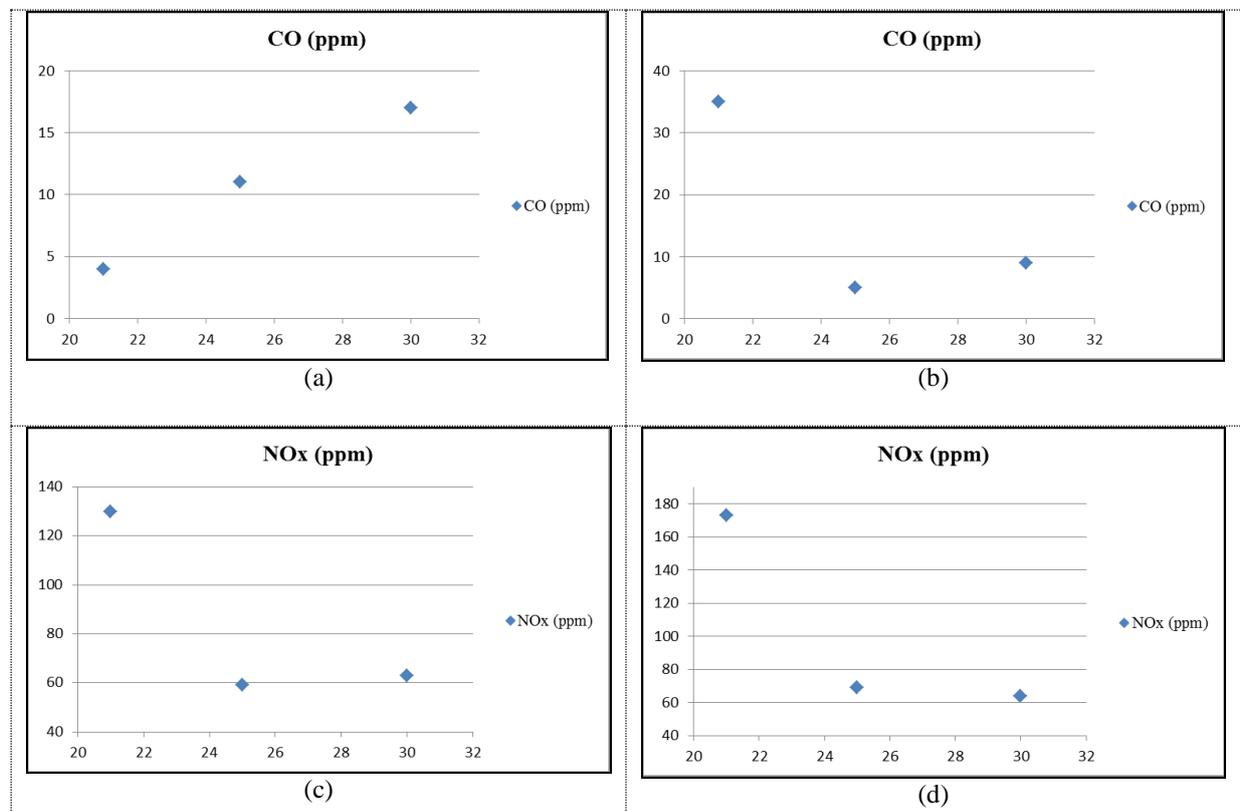


Figure 2. (a) CO versus Oxygen index for Equivalence Ratio 1.0 and frequency 0 Hz; (b) CO versus Oxygen index for Equivalence Ratio 1.0 and frequency 220 Hz; (c) NOx versus Oxygen index for Equivalence Ratio 1.0 and frequency 0 Hz; (d) NOx versus Oxygen index for Equivalence Ratio 1.0 and frequency 220 Hz.

Figure 3 shows the physical appearance of the flames in combinations of input variables. It is possible to observe that for conditions without oxygen enrichment there is an increase of the flame stability with the excitation of the sound frequencies, which do not remain anchored to the base of the burner, a condition known as "lifted flame", often leading to of the flame, which made it difficult to carry out the test under these conditions.

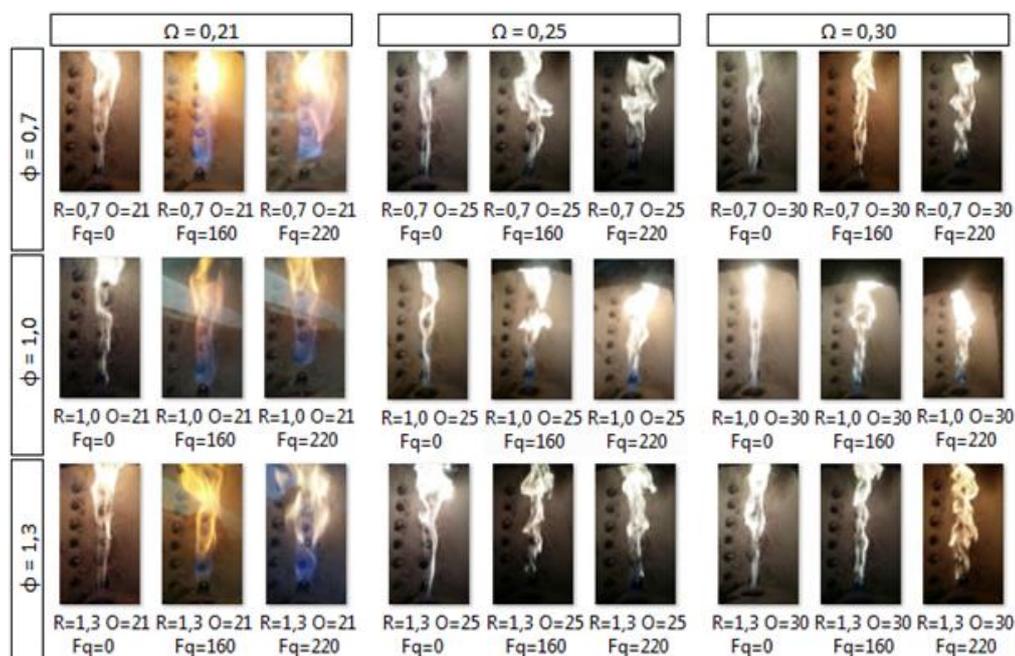


Figure 3. Flames appearances with correlations.

With the enrichment of the mixture with oxygen, the flame anchoring is greatly improved for the excited flame conditions with sound waves, possibly due to the characteristic of the OEC technique which increases the flammability limits of the fuel / oxidant mixture. Another characteristic observed is the increase of the apparent turbulence of the flame with the entrance of the acoustic field, besides the bluish aspect in some regions of the flame, characteristic of absence of soot.

The best operating condition for the developed experimental burner is in the stoichiometric condition with the oxidant with 25% of O_2 and with acoustic excitation of 160 Hz. This operating condition reflected in CO emissions of 14 ppm, NO_x of 37 ppm and one Exhaust gas temperature of $205^\circ C$. With this, the possibility of using the OEC and pulsed flame techniques together to simultaneously reduce the CO and NO_x emissions, as well as the exhaust gas temperature, was evidenced.

4. CONCLUSIONS

It was possible to observe a general tendency of reduction in the CO emissions with the enrichment of the oxidant with O_2 and also in some conditions with acoustically excited flame. It was also evidenced the antagonistic behavior of the NO_x concentration with that of CO, where under conditions of operation with reduction of carbon monoxide there was increase of nitrogen oxide. Such behavior reveals the importance of finding a working condition for combustion devices where there are optimized emissions of pollutants.

The optimum operating condition found for the experimental device (and 160 Hz) shows that OEC and pulsed combustion techniques applied together and in a controlled manner can bring gains to reduce pollutant emissions and increase the efficiency of thermal equipment at Since this condition combines the enriched oxidant at 25% O_2 which reduces CO emissions, coupled with an improvement in the fuel / oxidant mixture rate due to sound excitation at the 160 Hz frequency, also reducing NO_x concentrations.

5. ACKNOWLEDGEMENTS

This work was supported by SENAI CIMATEC and CNPq.

6. REFERENCES

- Baukal, Jr., C. E. Oxygen-Enhanced Combustion. 1a ed. New York: CRC Press, 1998.
- Chao, Y. C; Ming-Shan, J. Behavior of the lifted jet flame under acoustic excitation, *Symposium (International). Combustion*, v. 24, p. 333-340, 1992.

- Chao, Y. C.; Yuan, T.; Tseng, C. S. Effects of flame lifting and acoustic excitation on the reduction of NO_x emissions, *Combustion Science Technology*, p. 113-114, 1996.
- Demare, D.; Baillot, F. Acoustic enhancement of combustion in lifted nonpremixed jet flames, *Combustion Flame*, v. 139, p. 312-328, 2004.
- Ferreira, D.S. Queimadores pulsantes para baixas emissões de poluentes. Dissertação (Mestrado em Transmissão e Conversão de Energia) - UNESP, Guaratinguetá, 2001 (in portuguese).
- Kim, M.; Choi, Y.; Oh, J.; Yoon, Y. Flame-vortex interaction and mixing behaviors of turbulent non-premixed jet flames under acoustic forcing, *Combustion Flame*, v. 156, p. 2252-2263, 2009.
- Lovett, J. A.; Turns, S. R. Structure of pulsed turbulent nonpremixed jet flames, *Combustion Science Technology*, v. 94, p. 193-217, 1993.
- Saito, M.; Sato, M.; Nishimura, A. Soot suppression by acoustic oscillated combustion, *Fuel*, v. 77, p. 973-978, 1998.
- Toong, T. Y.; Richard S. F.; John, S. M.; Griffin, A. Y. Mechanisms of combustion instability, *Symposium (International) Combustion*. v. 10, p. 1301-1313, 1965.

7. RESPONSIBILITY NOTICE

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