INDUSTRIAL BURNERS TESTING AND COMBUSTION EFFICIENCY ANALYSIS

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ABSTRACT

This paper describes experimental procedures and techniques adopted for combustion analysis during the testing of burners for industrial applications. The tests were carried out in the Combustion Technology Laboratory (NTC) of the University of Fortaleza. The NTC facilities are composed basically of experimental testing hall, a monitoring room, a chromatography laboratory and a modeling and simulation studies room. In the lab testing hall, is installed a test bench composed basically of the following parts : a combustion chamber with nominal thermal capacity of 1.000.000 kcal/h, two fully instrumented gas and air supply sections, a gas analyzer for emissions measurement, a panel for monitoring of water supply to combustion chamber coil, a cooling tower for heat delivery of combustion chamber. A data acquisition and control system is available with all the hardware tools for monitoring of the combustion process. With all the acquired measurements of temperature, flow rate, pressures, emissions, etc., the First Law energy balance approach was used in order to evaluate the combustion efficiency of two different burners with 378.000 and 403.200 kcal/h nominal heat power. Analysis of preliminary results allows representing the burners efficiency according to different air and fuel operating conditions. The experimental data obtained are also compared with simulation results from the modeling of the combustion process, presented in another article linked with this work, where a discussion of such comparison is made. Future studies will be dedicated to the development of improved efficiency combustion systems for industrial and commercial applications.

INTRODUCTION

Combustion and its control is a primary importance to the survival of our planet. Basically almost 80 % of the human activities on earth relies on some kind of combustion process as for example, the generation of electricity, transportation, industries, commerce, and services. On the other side of the beneficial aspects of combustion there is the associated problem of environmental pollution. The major pollutants produced by combustion are unburned and partially burned hydrocarbons, nitrogen oxides, carbon monoxides, sulphur oxides and particulates under various forms.

Governmental regulations on emissions standard are being more and more stringent, depletion of fossil fuels is just on the rear-mirror, and the competitiveness of the global new order demand scientists and engineers to be more focused on problems of combustion.

With the above related situation on mind, the University of Fortaleza through governmental help constructed the NTC (Combustion Technology Laboratory) a laboratory were the present work was carried out. The experiments described hereafter are related with industrial burners performance testing, and represents the startup on research activities at the NTC, in the field of applied combustion.

Two burners were tested for different operating conditions, using an experimental combustion chamber. The experimental testing data was used in order to evaluate burners efficiency and emissions characteristics, according to air to fuel ratio.

Analysis of the acquired data and computed results are consistent with theoretical expected results, showing by this way that the methodology applied was adequate.

EXPERIMENTAL FACILITIES AND TESTING SET-UP

Figures 1 and 2 show some views of the testing apparatus used in this work. The main component is a combustion chamber, equipped with all the accessory components and control required for burners operation. Although any gaseous fuel could be supplied to the chamber, only liquefied petroleum gas (LPG) was used in this work.

The combustion chamber has a cylindrical section with a diameter of 1600 mm, a height of 2500 mm, having a composed insulated wall with 200 mm thickness. The burner is mounted in the inferior section of the cylindrical section (as shown in Figs. 1 and 3), being connected to the gas and air supply/control racks.

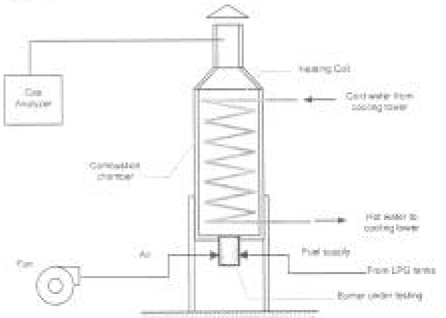


Fig. 1 - Schematic view of the combustion test bench.

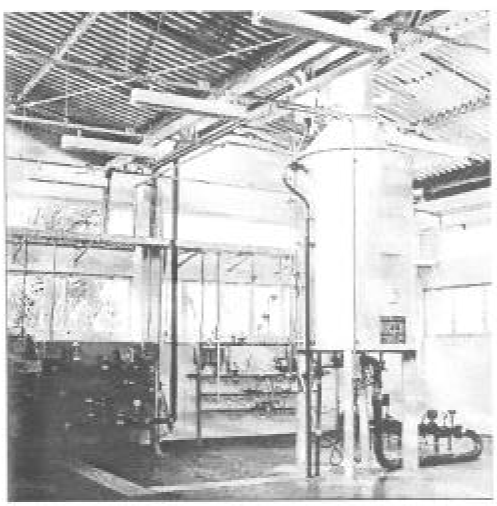


Fig. 2 - General view of the combustion test bench.

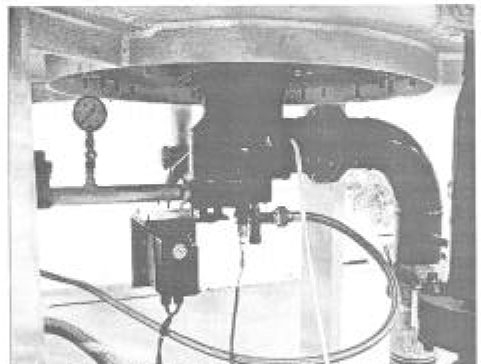


Fig. 3 - Mounting detail of the second burner tested using the combustion chamber.

	Burner 1	Burner 2
Thermal Capacity [BTU/h]	1600-2400	750-1600
Turndown ratio (with 75% excess air)	96:1	-
Flame length / Diameter [m]	12-24/8-12	12-30
Maximum excess air (%)	3100-4700 %	-

Table 1 - Main characteristics of the burners tested.

Two industrial burners (Fig. 4) were tested according the procedure described hereafter. Table 1 lists main characteristics for each burner.

A water heating coil is available inside of the cylindrical section of the chamber, in order to simulate useful heat output. The coil is connected with a cooling tower forming a closed water network.

All the experimental data from testing was measured by a instrumentation system consisting basically of type K thermocouples, turbine flow meters and pressure transmitters. All the analog signals from sensor transmitters were acquired by a PC based data acquisition and control system hardware.

Figure 5 below, shows a view of the PC screen developed within a commercial data acquisition and control software, in order to assist experimental tests with the combustion chamber.

THEORETICAL CONSIDERATIONS

In this work, liquefied petroleum gas combustion is considered. Although LPG composition consists of ethane, propane and butane, with different mixtures, a 100 % propane composition was assumed in this work. Considering complete propane combustion with a stoichiometric amount of air, the following reaction equation can be considered,

$$C_3H_8 + (5)(O_2 + 3{,}76N_2) \rightarrow 3CO_2 + 4H_2O + (5)(3{,}76)N_2 \quad (1)$$

Combustion air composition is assumed to be 21 percent O_2 and 79 percent N_2 (by volume). The stoichiometric air-fuel ratio ($AF_{C_3H_8,ST}$) for propane can be given by (Turns,2000),

$$AF_{C_3H_8,ST} = \left(\frac{m_{air}}{m_{C_3H_8}}\right)_{ST} = \frac{4{,}76 \cdot 5}{1} \cdot \frac{MW_{air}}{MW_{propane}} \quad (2)$$

where,

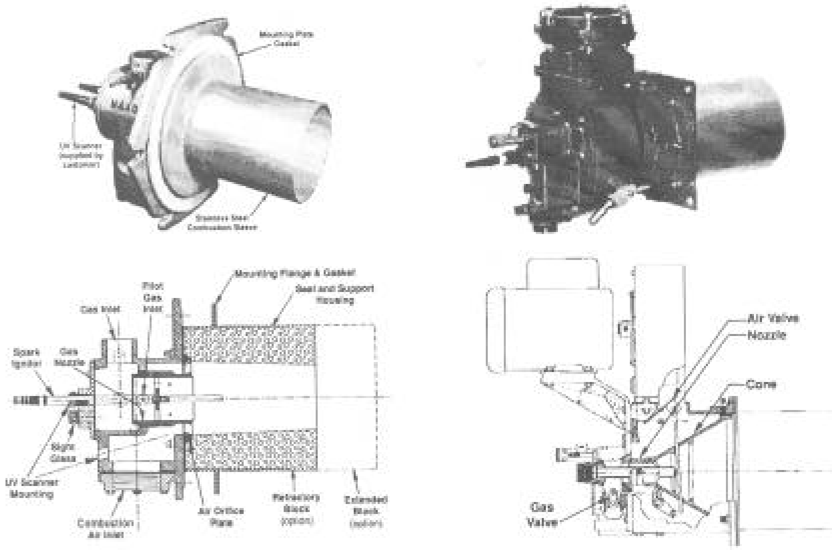


Fig. 4 - Burners 1 (left) and 2 (right) tested in the experiments.

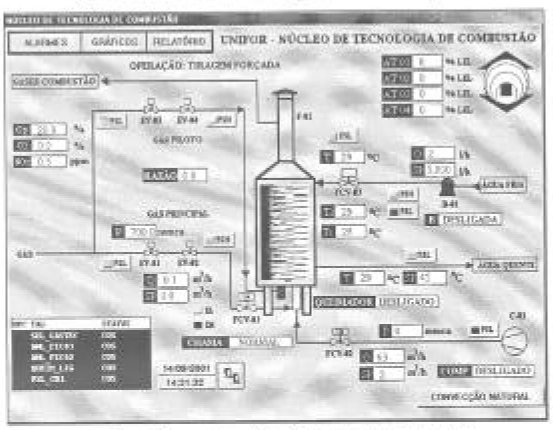


Fig. 5 - Screenshot of the PC based supervisory panel.

$AF_{C_3H_8,ST}$ propane stoichiometric air to fuel mass ratio (15,752)

$(m_{air}/m_{C_3H_8})_{ST}$ propane air to fuel mass ratio in stoichiometric conditions

MW_{air} air molecular weight (= 28,85)

$MW_{propane}$ propane molecular weight (=3.(12,01)+8.(1,008) = 44,094)

The equivalence ratio (Φ) is defined by the ratio between stoichiometric and actual air-fuel ratios as,

$$\Phi = \frac{AF_{C_3H_8,ST}}{AF_{C_3H_8,Act}} \tag{3}$$

where $AF_{C_3H_8,Act}$ Actrepresents the actual air fuel ratio.

According the value of Φ, the fuel-air mixture may be rich ($\Phi>1$), lean ($\Phi<1$), or stoichiometric ($\Phi=1$). The percent excess air in actual combustion systems is obtained with respect to Φ, by making,

$$EA_{\%} = \frac{(1-\Phi)}{\Phi}\cdot 100 \tag{4}$$

Considering an application of 1st Law energy conservation principle, to a control volume including the combustion chamber, as shown in Fig. 6, the following equation can be written (Borman, 1998),

$$\dot{N}_{air}\hat{h}_{air} + \dot{N}_{C_3H_8}\hat{h}_{C_3H_8} = \dot{Q}_w + \dot{Q}_{losses} + \sum_{j=1}^{J}\dot{N}_j\hat{h}_j \tag{5}$$

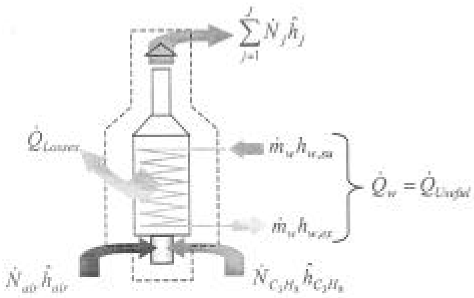


Fig. 6 - Energy balance for the combustion chamber cotrol volume

where, $\dot{N}_{air}\hat{h}_{air}$ and $\dot{N}_{C_3H_8}\hat{h}_{C_3H_8}$ corresponds to heat input from combustion air and fuel respectively,and $\dot{Q}_w$ is the heat transfer rate to water (useful heat), $\dot{Q}_{losses}$ is the heat losses from chamber walls, and $\sum_{j=1}^{J} \dot{N}_j \hat{h}_j$ is the heat output associated with combustion products.

In order to compute the combustion efficiency of the burners (η), useful heat output is taken as the heat transfer rate to water in the heating coil ($\dot{Q}_w$). In this case, we simply have,

$$\eta = \frac{useful\ heat\ output}{energy\ input} = \frac{\dot{Q}_w}{\dot{m}_f HHV} \qquad (6)$$

In the above equation, HHV represents the higher heating value of the fuel (for propane), $\dot{m}_f$ is the fuel mass flow rate, and $\dot{Q}_w$ is calculated making,

$$\dot{Q}_w = \dot{V}_w \cdot \rho_w \cdot C_w \cdot \left(T_{w,ex} - T_{w,in}\right) \qquad (7)$$

where, $\dot{V}_w, P_w, C_w, (T_{w,ex} - T_{w,in})$, are the water volumetric flow rate, density, specific heat and temperature difference between coil inlet and outlet.

Heat losses from combustion chamber walls to the surroundings were evaluated by considering free convection with ambient still air. The wall temperature of the chamber, was taken as an average about 50 °C (max.), while for the ambient air, an average temperature during the tests about 25 °C (min.) was considered.

For these temperatures, the Grashof number is about $3.40E^{10}$, which characterizes a turbulent flow condition. Then, a simplified correlation for natural turbulent convection heat transfer from a vertical cylinder (Holman, 83) was used, resulting in a convective heat transfer coefficient of 2,8 W/m^2.K. With this approach, heat losses from the chamber are of 873 W; a quite small value compared with the useful heat output (less than 1% aprox.).

A heat transfer analysis of the heating coil was also developed in this work. Several tests with different water flow rates, as well as, combustion conditions were made, allowing us to investigate some correlation for overall heat transfer coefficient. Results about this are shown in next section.

TESTING METHODOLOGY AND EXPERIMENTAL DATA

The testing methodology is based in the adjust of 3 operating conditions : (i) LPG flow rate, (ii) combustion air flow rate and (iii) coil water flow rate. Several tests were performed for different operating conditions combining these parameters. Fig. 7 below shows an overall view of the experiments carried out with respect to the range of air and fuel flow rates.

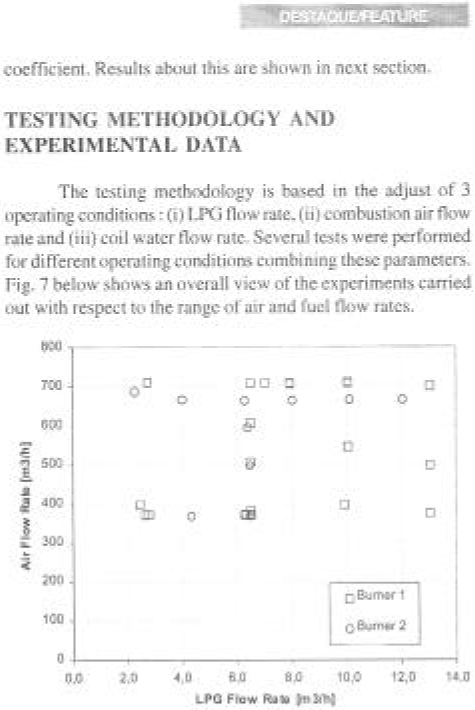


Fig. 7 - Air and fuel flow rate ranges for the tests.

Basically the testing procedure consists of adjusting an operating condition, i.e., setting the three desired parameters, and to wait until steady state establishment. Once stable operation is verified, some time interval is allowed in order to register a representative amount of data, before changing operating parameters for the next testing condition. Fig. 8 shows a typical testing run where air and fuel flow rate was changed for different experimental conditions.

EXPERIMENTAL RESULTS

With average measurements for each steady state operating conditions, the efficiency for each burner was calculated from Eq. (6) and plotted against the equivalence ratio (Φ) as shown in Figure 9. As it can be seen, combustion efficiency increases with Φ, and tends to some maximum stable value as Φ tends to unity.

Concerning efficiency of combustion against the equivalence ratio for both tested burners, as shown in the Fig. 9, its behavior is as expected, that is, for a lean mixture of fuel and air, the combustion efficiency will be lower than the maximum efficiency which will be attained when Φ equals unity.

In this article technical details of each burner will not be considered profoundly although as can be seen in Fig. 9, the combustion efficiency of the burner 1 shows a more harmonious tendency than the burner 2. Both are of premixed type burners. However, burner 2 shows a more consistent combustion efficiency than burner 1. This behaviour can probably be due to the way the air injected into the burner mixing chamber. In the case of burner 1, air enters the chamber in a swirled way and

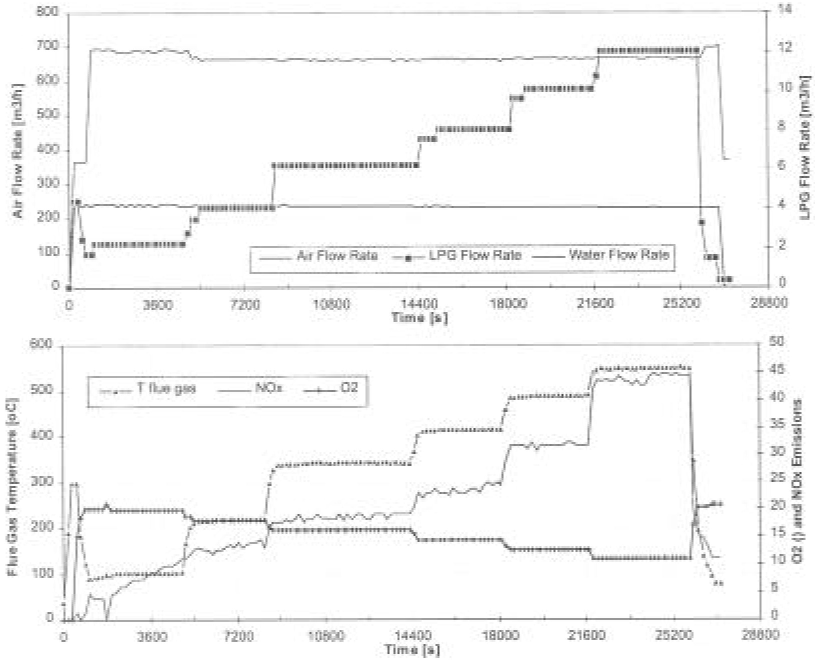


Fig. 8 - Changes of selected variables during a typical testing run. Above: LPG, air and water flow rates. Below: Combustion products temperatures, NOx and O_2 emissions.

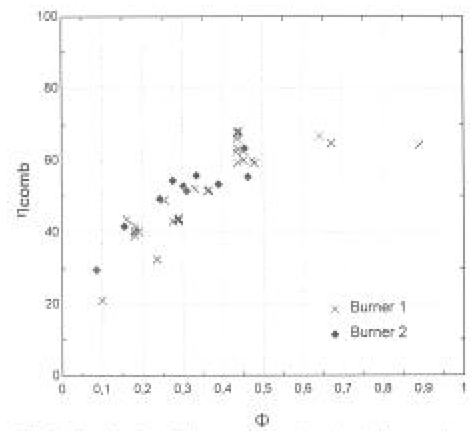


Fig. 9 - Combustion efficiency as a function of equivalence ratio.

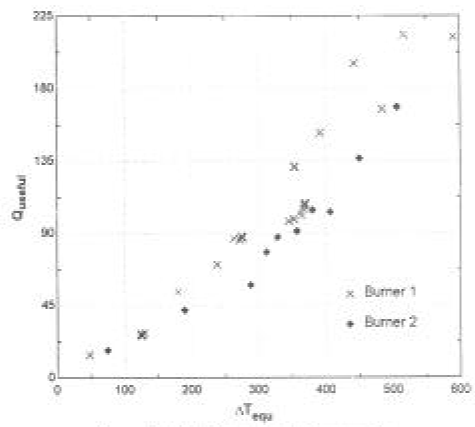


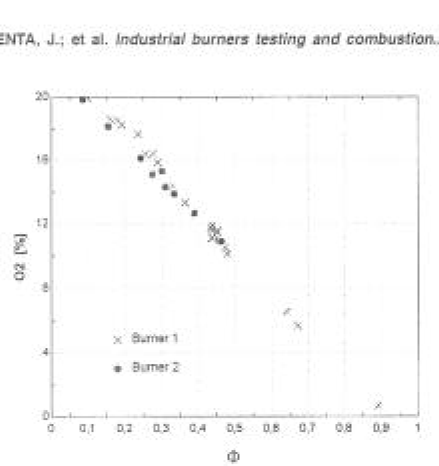
Figure 10 - Useful heat output change with equivalent temperature difference.

as for burner 2, air enters laterally through orifices in the wall of a conical section.

Although the main goal of the experiments is the combustion study, additional analysis was considered for the heating coil installed inside the combustion chamber.

Such data allow us to investigate possible correlation involving heat transfer coefficients, water flow and combustion condition.

Figure 10 shows the useful heat liberated by burner against equivalent temperature difference (considering temperatures for flue gas, water inlet and outlet). Such kind of representation allow to identify an overall heat transfer coefficient for the water heating coil about 318 W/K. Although, as seen in Fig. 9, burner 2 showed a harmonious behaviour of efficiency against equivalent ratio, burner 1 delivers a more pronounced useful heat as a function of ΔT_{equ} when compared with burner 2. This behaviour can be influential on the way the



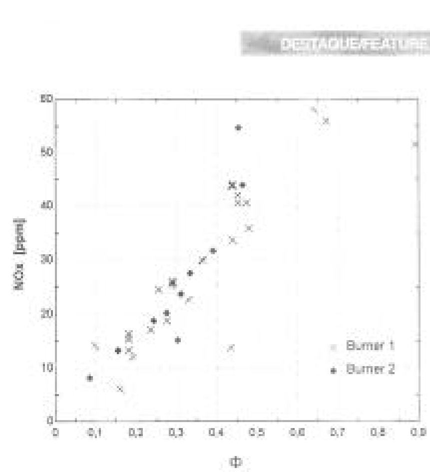


Figure 11 - Oxygen and (Left) nitrogen oxides (right) measured emissions as a function of the equivalence ratio.

burner is used, that is, the way the burner heats the process. On the case in which the delivered heat must be under strict control, the design of burner 2 will be appropriated, and, in the other case, the design of burner 1 will be recommended.

Figure 11 below presents a view of O_2 and NOx emissions measured during the tests, as a function of the equivalence ratio (Φ). The observed decrease of oxygen presence in combustion products, accordingly Φ increases, is in agreement with basic combustion theory and simply reflects the change from a excess ai condition (Φ<1) to a stoichiometric one (ϕ=1). The opposite behaviour is also expected for emission of NOx.

From Fig. 11. it is interesting to see that both burners have practically the same behaviour in the decrease of oxygen emission. Naturally the emission of O_2 as excess air percentage, express the needs of different technologies and applications as for example, agricultural products drying, but in any case for such application both burner would be appropriated. The same is not true when the control of NOx emission is desirable since as can be seen in Fig. 11, the burner 2, seems to show better conditions to accept technical modifications in order to reduce nitrogen oxides emissions.

CONCLUSIONS

A testing methodology for burners efficiency analysis was presented, using an experimental laboratory combustion chamber. After analysis of the acquired data, classical equations on combustion analysis were used in order to compute performance parameters. The experimental results obtained are consistent with theoretical expected results, allowing to consider the methodology applied as adequate.

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