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# Small size burner combustion stabilization by means of strong cyclonic recirculation

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## Abstract

The exhausted gas recirculation inside the combustion chamber represents a challenging strategy to stabilize the oxidation process for novel combustion processes that aim at reducing pollutants emission, controlling the system working temperature by diluting the fresh incoming charge, and keep high process efficiency. The mass and sensible enthalpy ratio of recycled exhausted gas represents a key parameter to promote and stabilize the oxidation process.

The chemical/thermodynamic features of the oxidation process were investigated by means of a numerical analysis. The process was schematized as a non-adiabatic constant-volume Continuous-flow Stirred-Tank Reactor (CSTR) where part of the exhausted gas was recirculated back to the reactor. The stability of the process was investigated as a function of the pre-heating temperature and of the dilution level of propane/oxygen/nitrogen mixtures for a fixed recirculation ratio.

Following, experimental tests were realized in a small size burner characterized by a strong internal recirculation ratio, induced by a cyclonic fluid-dynamic pattern obtained by the geometrical configuration of the reactor and of the feeding system. The facility was designed to independently vary the mixture pre-heating temperatures and the mixture dilution levels.

The experimental results suggest that the cyclonic configuration represents a challenging choice to stabilize the oxidation process in small-size applications. It contains the pollutants emission for a large range of preheating temperature – mixture dilution levels extending the burner operability conditions.

*Keywords:* Cyclonic burner; Diluted combustion; Combustion stability; Internal recirculation

## 1. Introduction

Gas recirculation has been used for a relatively long time to stabilize combustion processes in several practical systems. To this aim several configurations have been considered based on fluid-dynamic stabilization by swirling or other

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strongly convoluted flow fields, as well as on external and internal gas recirculation or regenerative systems, trapped vortex [1–4].

Of course, this issue is directly related to the main requirements that a combustion process has to satisfy, related to its efficiency in terms of low pollutant emission, energy saving and fuel flexibility. These constrains, imposed by the energy market fast changing requirements, give rise to the need of defining new and advanced solutions allowing to use, in the same unit, a broad range of energy carrying molecules (i.e. fuels), according to local and time market offer while preserving combustion efficiency and eco-sustainability.

It is well assessed that recirculating heat and/or combustion products can have beneficial effects not only on flame stability but also on pollutants production. More specifically, in the last years several combustion modes inherently based on a strong recirculation process have been proposed and some of them found their way to commercial use. Typical examples are MILD, HiTAC and other regenerative burners (FLOX) [5–9] but also high intensity combustion devices have been proposed that rely on quite similar concepts [10–12].

One of the main limitations to the large deployment of recirculation based combustion devices is the difficulty in stabilizing small scale systems due to the increasingly higher heat losses in small scale systems. The reduced volume of the combustion chamber lead also to very short residence time inside the combustor implying an increasing of pollutant emissions and a reduction of the operational limits of such systems. For such reasons they would find their best exploitation in local “production and consumption” arrangements that maximize the chain efficiency while limiting environmental impact and helping preserving the $CO_2$ neutrality. These plants are thus of reduced size and this poses the problem of identifying combustion units capable of achieving reasonable efficiencies while keeping pollutant production at a compatible level at a rather small plant scale.

Previous considerations pose the problem of identifying suitable configuration and geometries capable of realizing stable, efficient and clean combustion processes on small scale preserving a reasonable degree of simplicity. In this study we consider a configuration that can be considered ancillary both for the study of recirculation systems and recirculation zone in a full scale system as well as small scale burner configuration.

In previous investigations on a small-scale cyclone burner [13,14], the achievement of MILD combustion conditions in systems externally diluted in $N_2$ or $CO_2$ was demonstrated and they showed that a cyclonic flow motion provided large residence time and enhanced the mixing between the reactants.

The performance of such a combustor was investigated in further detail resulting in favorable combustion and stability characteristics for small-size power generation technologies.

After an introductory numerical analysis of the sustainability of a combustion process in a recirculated burner, combustion performances of the cyclonic burner are analyzed to point out advantages and possible drawbacks of the burner as well as suitable working conditions and performances.

## 2. Burner size and process sustainability

In this section a numerical analysis will be presented with the aim of identifying admissible thermal power for burners with internal gas recirculation fed with increasing external dilution levels and different pre-heating temperatures. The system was schematized (see the scheme in upper right corner of Fig. 1) as a non-adiabatic constant-volume Continuous-flow Stirred-Tank Reactor (CSTR). Part of the exit gases are recirculated back to the reactor to consider the mass and sensible enthalpy feedback mechanisms provided by the recycled exhausted gases to stabilize the oxidation process. Numerical integrations were performed using the AURORA application of the ChemKin 3.7 [15] software and the $C_1C_3$ kinetic mechanism [16] for a stoichiometric (equivalence ratio equal to 1) $C_3H_8/O_2/N_2$ mixture. Pre-heating temperature $T_{in}$ was changed from 300 K up to 2000 K and the nitrogen content $X_{N_2}$ from 0.758 (which corresponds to the nitrogen content in air at an equivalence ratio $\Phi = 1$) up to 0.98. The mass recirculation ratio $K_v$ was fixed at a value of 5 that corresponds to an average value of $K_v$ [17, 18] of existing practical devices. System volume ($V_o = 2000\ \mathrm{cm}^3$) was adjusted to keep constant the averaged initial residence time $\tau_0$ at a value of 0.5 s.

The numerical results were reported in Fig. 1 in a *dilution level – thermal power* plane, where the iso-preheating temperature lines are reported. As expected, thermal power diminishes with both increasing the inlet temperature (due to the reduced gas density in the reactor) and the dilution level of the mixture (due to the higher inert gases concentration in the reactor).

In Fig. 1 it is clearly observable that for low $T_{in}$ and for high $X_{N_2}$, a “no ignition” zone can be numerically identified. In contrast, at pre-heating temperatures higher than a threshold value ignition and oxidation processes take place in a stable and sustainable manner. Temperature threshold value increases passing from $T_{in} = 785$ K for the air condition ($X_{N_2} = 0.758$) to 950 K for $X_{N_2} = 0.98$. The “sustainable” zone enlarges with the pre-heating temperature while narrows with the mixture dilution level.

Within the “sustainable” zone, a region of “incomplete combustion” is identified on the basis of the comparison between two characteristic times, the real residence time ($\tau_{res}$) and the oxidation

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