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# Study of the performance of a catalytic premixed meso-scale burner

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ABSTRACT

Portable electric devices have been object of interest of the scientific community for their application in different areas. The development of catalytic combustors coupled with thermo-electric devices is particularly attracting for combustion stability and safety. In this work a novel premixed catalytic meso-scale combustor fueled with propane/air mixture has been designed and tested. The wafer-like combustor is filled up with commercially-available catalytic pellets of alumina covered with platinum (1% weight). As a preliminary investigation the stability limits have been investigated. The analysis of the temperature values and distribution across the combustor surfaces have been carried out with thermocouples, for local measurements, as well as with an IR camera, for 2D measurements. Moreover, concerning combustion processes, the chemical composition of the exhaust gases have been derived by performing FT-IR measurements. This quantitative analysis allows obtaining the overall chemical efficiency of the catalytic combustor. As a further analysis, the effect of aging of catalytic coating on the overall combustor performances has been investigated. The configuration under study has been proved to be suitable for the coupling with thermo-electric devices.



## 1. Introduction

In the last few years the miniaturization of mechanical and electromechanical engineering devices have received growing attention, thanks to the interest registered in the areas of microelectronics, biomechanics, and molecular biology and largely also to the progress made in microfabrication techniques [1]. The interest in producing miniaturized mechanical devices opens exciting new opportunities for combustion, especially in the field of micro power generation [2,3], because of the need for power-supply devices with high specific energy (small size, low weight, long duration) [4,5]. This is further boosted by the desire to replace batteries with hydrocarbon-based fuels due to their higher energy density and to provide portable power sources [6–8]. Even at 10% energy conversion efficiency hydrocarbon fuels can provide 10 times the energy density of the most advanced batteries [7–9]. The growing interest in hydrocarbon-based sources for decentralized power generation and as replacements of existing batteries has spawned a significant research effort in small-scale homogeneous combustion [9–16] and catalytic reactors [17–22]. These micro chemical systems are used either for generation of hydrogen for fuel cells [23–27] or for direct conversion of thermal energy released via combustion to electrical energy using thermoelectric or thermo-photovoltaic devices [28,29].

Concerning the conventional homogeneous (gas-phase) combustion, the major disadvantage is essentially the very high (>1500 °C) operating temperatures. These high temperatures greatly limit material selection, and require extensive combustor insulation. Moreover, further strong limitations of these devices are strictly related to their dimensions. In fact, as the size decreases, the surface area to volume ratio of the combustion device increases with a subsequent increase of the heat loss to heat generation ratio. These strong losses in the small dimension induce flame quenching [1–3], and are also responsible for an increase in pollutants emission such as CO and unburned hydrocarbons. In addition, the smaller the volume the shorter the flow residence time.

To overcome such limitations, catalytic combustion seems to be the most suitable solution. In fact, when implemented in micro-meso scale devices, catalytic combustion allows fully utilization of the high energy densities of hydrocarbon fuels, but at notably lower operating temperatures. Additionally, catalytic systems are generally easier to start, more robust to heat losses, and self-sustained at leaner fuel/air ratios.

In order to investigate the overall performance of a catalytic micro/meso-scale combustor, the analysis of the exhaust gases is required to derive the chemical efficiency. Fourier transform infrared spectroscopy (FT-IR) has been widely applied for quantitative

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**Nomenclature**

| | |
|---|---|
| $\eta c$ | chemical efficiency (dimensionless) |
| $\Phi$ | equivalence ratio (dimensionless) = $\frac{(O/F)}{(O/F)_{stoich}}$ |
| $T$ | temperature (°C) |

measurements of gas species concentrations at the exhaust of vehicles [30,31]. Anyway, only few works are reported in the literature regarding the application of the FT-IR technique to measure gases concentration at the exhaust of a meso-scale combustor. Wu et al. in a recent work [32] performed FT-IR measurements for exhaust gas analysis of a meso-scale vortex-stabilized combustor.

In the present work, a premixed catalytic meso-scale combustor has been developed for coupling with thermo-electric devices. The chemical efficiency of the system was evaluated for different inlet mass flow rates. To this purpose, measurements of the combustor exhaust gases concentration were performed by applying FT-IR spectroscopy. Moreover, the analysis of the temperature values and distribution across the combustor surfaces have been carried out with thermocouples, for local measurements, as well as with an IR camera, for 2D measurements. The meso-combustor developed for this work has some notable advantages when compared to similar solutions presented in the literature [5–7]. The first advantage is the use of a low-cost, commercially available catalyst, with no need for ad hoc manufacturing. The second important advantage is that the use of such a catalyst allows obtaining the desired wall temperatures for thermo-electrical device coupling with no need for wall insulation from higher temperatures, thus resulting in smaller fuel consumption.

## 2. Materials and methods

Tests were performed using a catalytic premixed meso-scale combustor, sketched in Fig. 1. The combustor geometry was chosen so that the combustion chamber area coincides with the surface of the thermoelectrical devices selected for coupling. The aluminum-made combustor is a 40 mm × 40 mm × 4 mm chamber filled with commercial cylindrical pellets of alumina covered with a thin catalytic film (platinum 1% weight). Pellets height is 3.2 mm; pellets base radius is 1.6 mm. The combustion chamber is filled with 154 pellets placed in ordered lines, so that the channel for gas flowing is the difference between the chamber height and the pellets height, i.e. 0.8 mm. Propane and air are used as fuel and oxidizer for combustion reaction in the chamber, and the related mass flow rates are measured and controlled by using thermal mass flow meters (Bronkhorst El-Flow F-201CV). Moreover, as $C_3H_8$/air mixture is not self-igniting in contrast with $H_2$/air mixture, Hydrogen assisted ignition is performed: after starting the ignition with hydrogen and air mixture flowing in the combustor, a gradual replacement of hydrogen with propane is carried out.

The meso-scale combustor was designed and tested for portable electricity production via thermo-electrical device coupled with the combustor. Tests were performed in order to assess the feasibility of the meso-scale combustor for such a use.

To this aim, the overall combustion efficiency was estimated performing FT-IR analysis of the exhaust gases. At the combustor outlet, the exhaust gases are sampled and properly sent through an heated transfer line, equipped with a cut-off particulate filter, to a Fourier transform infrared spectrometer (Thermo Scientific Nicolet 6700) as shown in Fig. 2. As for gas phase analysis a variable-pathlength heated gas-cell (Gemini Mars series 6.4M, internal volume of 0.75 l) is used and positioned inside the instrument. In order to prevent possible carbon-residuals condensation, both the transfer line and the gas-cell are temperature controlled and maintained at 393 K. Since the mass flow rates used are very small, particular care has been taken for the sampling system. In fact, in order to avoid exhaust gases dilution with ambient air, the suction mass flow has been regulated with a valve in order to be lower than the outlet mass flow. Moreover, in order to avoid the entrance of water in the measuring cell, a water trap is properly positioned on the sampling system. For each condition under study the IR spectrum results from the average over 64 acquisitions, with a resolution of 0.5 $cm^{-1}$, and background subtraction, this last

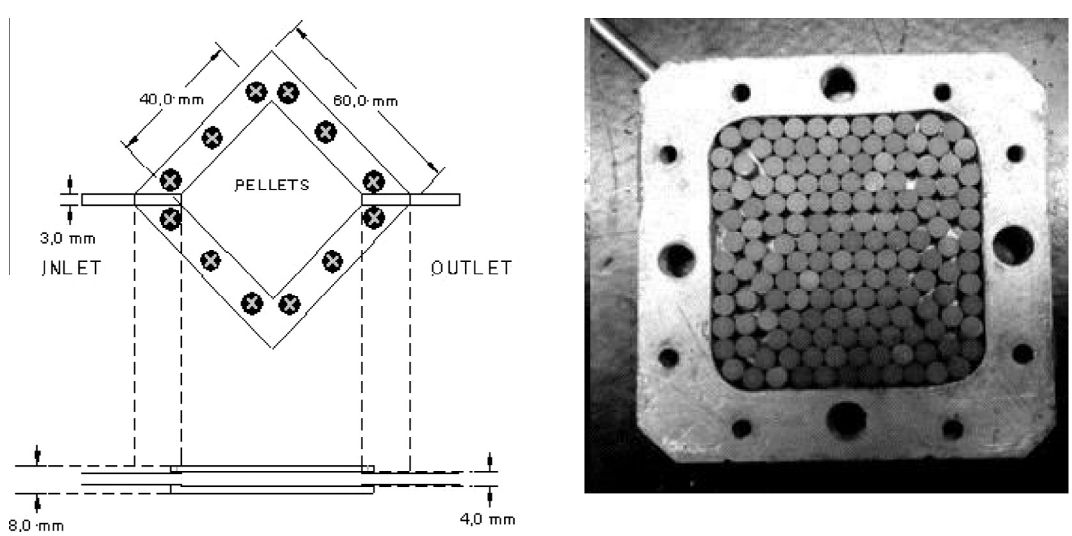


**Fig. 1.** Sketch of the micro combustor used for this work (left), and a picture showing the pellets placed in the combustion chamber.