# Experimental Thermoelectric Generation in a Porous Media Burner

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Abstract—An experimental study on combustion in porous media and thermoelectric generation was performed. The reactor was composed of two types of porous media where flame stabilization was reached at the interface of them. An external thermoelectric module was placed to harvest the thermal energy produced in the system. Maximum values of voltage and current obtained were 503 mV and 150 mA respectively.

*Index Terms*—Energy conversion, super adiabatic combustion, thermoelectricity.

# I. INTRODUCTION

Filtration combustion (FC) is generated when an incoming fuel/oxidizer mixture flows and reacts in the interstitial space of a porous matrix. Due to its better thermal properties, the porous material allows efficient redistribution of the energy released in the gas-phase chemical reaction [1]. In particular, energy feed-back from the hot products of combustion to the upstream region preheats the reagents and generates temperatures above the normal adiabatic limits for free flames. The excess of enthalpy generated allows sustained combustion for extremely low-calorie mixtures [2]-[4].

In the low-velocity regime of FC, classification given by [5] thermal and reaction waves propagates through the porous matrix at velocities of order 10<sup>-4</sup> m/s. Propagation of reaction wave may occur either downstream or upstream, as pointed by analytical relations [2], [3], [5]-[8], numerical simulations [9], [10] and demonstrated with experimental results [11]-[13]. Upstream wave propagation leads to temperatures under the normal adiabatic conditions, producing the so-called subadiabatic effect. Stationary waves (immovable relative to the porous medium), exhibit equilibrium temperatures equal to normal laminar flames. Downstream wave propagation produces equilibrium temperatures above the normal adiabatic ones, giving the superadiabatic effect. Combustion front displacement direction depends mainly on fuel equivalence ratio, combustion enthalpy and heat exchange between solid and gas phase. As a result, if heat generation on the front exceeds heat absorption by porous media internal surface, the combustion front displaces

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against gas filtration. On the contrary, dealing with lean mixture or combustibles with low calorific power, the combustion front displaces downstream.

Due to the unsteady nature of the FC phenomenon, confinement methods for the combustion front are necessary. From the alluded methods, it can be mentioned the reciprocal flow burner [14], [15], and stabilization based on the modified Peclet number for reactors with two sections of porous materials with different properties [7], [12], [16].

The use of thermoelectric elements to produce electricity as a direct conversion system from thermal energy provides several advantages: environmental friendliness, silent operation, no mechanical moving parts, no operating fluid employed, long life performance period [17]-[19]. However, the main drawback of the use of thermoelectric elements is its low conversion efficiency [20].

Thermoelectric generators operate by utilizing the Seebeck effect: a temperature difference across two jointed, but different, conducting materials will create a voltage. In order to further increase the voltage and power output, the temperature difference may be increased by increasing the hot-side temperature or decreasing the cool-side temperature across the device. Therefore, for a burner utilizing thermoelectric devices, the power generated can be maximized by increasing the combustion temperature, or by cooling the cool-side of the device through either passive means, like a heat-sink, or active means, like a fan or impinging air jet. It is standard to connect multiple thermoelectric devices together in series to increase the voltage and power outputs.

Coupling of an efficient combustion system and a thermoelectric generator is an attractive alternative to bring power to areas where, due to its nature, no electrical connection to a power grid can be realized. Among the systems devised can be cited: the combustion-thermoelectric tube [21], the catalytic micro-combustor with integrated thermoelectric elements [22], the reciprocal flow thermoelectric porous burner. The latter has been studied both numerically [23], [24] and experimentally [25].

The present work focuses on thermoelectric generation using a porous media burner with flame stabilization at the interface of two porous bodies.

### II. SYSTEM DESCRIPTION

The prototype reactor is composed of a rectangular steel casing (A36) to house there the porous sections with dimensions,  $7 \times 7$  cm<sup>2</sup> outer square section, 25.4 cm length, 5.08 cm internal diameter, see Fig. 1.

Two highly porous pure alumina (99.5 wt% Al<sub>2</sub>O<sub>3</sub>)

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reticulated foams (76.2 mm long and 50.8 mm in diameter, porosity of 80%, 20 ppi, Fig. 2D) placed at the downstream section of the reactor (Manufacturer: Süd-Chemie Hi-Tech Ceramics, Louisville, KY). A lower-porosity alumina honeycomb porous media (400 cells per square inch, Fig. 2A) placed at the upstream section to keep the flame confined (Manufacturer: Applied Ceramics, Laurens, SC).



Fig. 1. Schematic of porous burner assembly



Fig. 2. Alumina reticulated (D) and honeycomb (A) porous foams

A thermoelectric module (TEM, Fig. 3) to harvest the heat released by combustion. The current work uses a commercially available  $Bi_2Te_3$  alloy module. It has a maximum no-load power output of 7.5 W, electrical resistance 0.9  $\Omega$ , hot side temperature limit of 300 °C, cold side 180 °C. (Model number 1261G-7L31-05CQ, Custom Thermoelectric). As additional insulation, a quartz piece was placed between the TEM and the reactor surface. An external electrical resistance to generate the matching condition in the system for maximum conversion efficiency.

Two hot wire anemometer flow controllers to measure the incoming air and fuel flows, capacity 250 l/min and 50 l/min respectively (Models FMA-2611A, FMA-2609A Manufacturer: OMEGA Engineering Inc., Standford, CT).

Three C-type (Fig. 4) and two K-type thermocouples that registered temperatures inside the reactor and in the interface

reactor surface-TEM, respectively.



Fig. 3. Thermoelectric module 1261G-7L31-05CQ of the custom thermoelectric company



Fig. 4. Porous media and thermocouples disposition in the burner.

A Data acquisition system model OMB DAQ 56, USB interface, 10 channels for register system temperatures. An air compressor Schulz, model MSV6/30 to propel air. A multimeter EXTECH model MV-110 to register currents and voltages in the system. Kaowool ceramic fiber insulation to cover internal and external surfaces of the reactor, see Fig. 5. Fuel composition was 96.86 wt% propane, 1.80 wt% Butane, 1.60 wt% ethane.



Fig. 5. Prototype burner assemby.

# III. RESULTS

# A. Experimental Procedure

The burner was fed initially with a stoichiometric air/fuel mixture at a total volumetric flow rate of 27 l/min. Ignition of the gas mixture was through an external flame placed at the top of the reactor. With these operational conditions, upstream flame propagation was observed.

When the flame reached the interface of the porous bodies with different porosity, if there was no indication of interface flame stabilization, the fuel composition was decreased maintaining the total volumetric flow rate constant. This procedure was repeated for equivalence ratios 1.0, 0.9, 0.8, 0.7, 0.6, 0.5 and 0.4. Values of equivalence ratio below 0.5 did not produce stable combustion.

Once the operational variables for which the flame stabilizes at the interface were found, the TEM was installed on the reactor surface over quartz insulation. An external electrical resistance for matching condition and the multimeter were connected. Dimensions of the TEM are  $40.0 \times 40.0 \times 3.4$  mm.

## B. Experimental Results

As the thermoelectric elements have a limit on the value of the maximum temperature, it is first searched a lean mixture (composition and velocity) that fulfills two main objectives: stopping the combustion front at the interface between the two porous media, such as those of Fig. 4, and developing the burner stationary temperature field with thermal levels below the limit on the thermoelectric elements.

With the outcomes of various tests, it was found that the flows of air and propane 26.4 and 0.56 1 / min respectively, giving  $\Phi$ = 0.5, both objectives were achieved. Developed temperatures are presented in Fig. 6: the three thermocouples were installed so that they can touch the porous bodies through the iron shell (Fig. 4). The first thermocouple was installed at half the height of the first ceramic, the second at the interface between the different porous bodies and the third at half the height of the second ceramic.



Fig. 6. Stationary temperatures along the burner for  $\Phi = 0.5$ .



Fig. 7. Temperature evolution in thermocouples for equivalence ratio 1.0.



Fig. 8. Temperature evolution in thermocouples for equivalence ratio 0.5.



Fig. 9. Temperature evolution in thermocouples for equivalence ratio 0.4.

Figs. 7-9, show thermal profiles evolution registered with the C-type thermocouples in the flame stabilization phase of the study. It can be seen that only for the case of equivalence ratio of 0.5 (see Fig. 7) the flame is stopped at the interface since interface thermocouple register the higher thermal level at approximately 4000 s compared to the up and downstream thermocouples. In Fig. 7 at approximately 1090 s, it can be seen that the flame passes the interface and keeps propagating in the upstream direction. It is clear from Fig. 9 that the flame does not reach the interface for its stabilization to take place.



Fig. 10. Voltage evolution for equivalence ratio 0.5.



Fig. 11. Current evolution for equivalence ratio 0.5.



current obtained. It can be seen that the voltage and current peaks were 0.503V and 0.15A, respectively, so that the electric power of 0.075 watts was reached. If the reactor surface was entirely covered the burner can theoretically give 1.5 watts of electrical power.

Clearly, the power achieved is not very high, but it represents the first attempt and marks the beginning of a series of works currently conducted at the University of Santiago de Chile to achieve better and more interesting results from the application standpoint.

# IV. CONCLUSION

Combustion flame stabilization was effectively achieved at the interface of two porous materials of different thermophysical properties for an equivalence ratio value of 0.5. Coupling of thermoelectric energy harvesting at the flame stabilization conditions, gives maximum values of voltage and current 503 mV and 150 mA respectively.

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