Blucher

# The combustion front propagation: thermo-chemical structure by temperature in the bed and gas analysis.

Monhol, F. A. F.[1]; Martins, M. F.[2]

1 Coordination of Mechanical Engineering, Federal Institute of Espírito Santo - IFES, São Mateus, ES, Brasil.

2 Post-Graduate Program in Mechanical Engineering, Federal University of Espírito Santo, Vitória, ES, Brasil

## Abstract

This paper analyzes the combustion front structure and the schemes of combustion in a co-current propagating process and the characteristics of the front propagation itself. For the experiments a fully instrumented reactor of reactive porous medium combustion with gas micro-sampling system was used. A new method to analyze the combustion front propagation based on the concentration of CO2 and O2 and in the bed temperatures was used. Therefore a thermo-chemical structure of the front propagation was developed. The size of the reaction zone obtained with the new method was 10.83 cm. Furthermore, there seems to be two basic schemes for the reaction process: in the early prevails oxygen-limited combustion and in the end reaction-limited combustion. Thus, the results are of great contribution to the knowledge of the combustion process in a reactor of reactive porous medium combustion.

Keywords: combustion front, thermo-chemical structure, gas analysis.

## 1. Introduction

The description of the behavior of a combustion front in reactive porous medium remains a great challenge to researchers in terms of physicochemical and heat and mass transfer. Many studies are focused on determining the factors that influence the progress and structure of a combustion front propagation.

WANG *et al.* [1] shown that smoldering combustion front propagation and its temperature increases with air flow. SHIN and CHOI [2] proposed two fixed bed combustion modes based on the oxygen availability. Oxygen-limited combustion: In this case, the fuel reaction rate is determined by the oxygen supply rate. Reaction-limited combustion: the reaction rate cannot increase due to further reaction rate limit and, therefore, may be noted the bed cooling by air convection. YANG *et al.* [3] observed that the composition of $CO_2$ and $O_2$ in the products depends on several factors such as air flow, fuel moisture, among others.

MARTINS [4] found the chemical structure of the front and the size of the reaction zone for oil shale using a method based on the concentration of chemical species in the reactor length.

In the present work it was proposed a new form of analysis through the evolution of the concentration of chemical species in a fixed point of the bed during the front propagation time together with the front propagation speed obtained of the temperature data. Thus, it is suggested not to identify a chemical structure of the front, but a thermo-chemical front structure, since data involves chemical species concentration and bed temperature data. Moreover, it was possible to obtain the compositions of the products formed and identified in each case two systems present in the combustion bed.

## 2. Methodology

The behavior of the combustion front was studied in a fixed bed reactor designed and built by MONHOL *et al*. [5]. It consists of a vertical cylindrical combustion chamber of 91 mm internal diameter and a height of 450 mm. It is made of a 2 mm thick stainless-steel material, surrounded by insulating material. A group of eight in-line thermocouples 1.5 mm in diameter and 122 mm length are located at Z = 0, 45, 90, 135 and 225 , 270, 315, 360 mm (measured from top to bottom of the reactor), allowing to measure temperature along the axis of the cell at different heights. The micro-sampling system connected to the gas analyzer that measures the volume fraction of gaseous combustion products with real-time acquisition, has two distinct points, one located at the bottom of the reactor and the other in the half height of the reactor in the central position of the

bed. In the half cell height, where the front suffers less interference from the ignition and the outlet of the reactor, the micro sampling system consists of a micro-tube with 1.5 mm diameter which allows a satisfactory sample without significant interference in the front propagation. This system was essential to characterize the chemical structure of the combustion front.

The characterization of the combustion front structure was possible by gas analyzing in the micro sample at half height of the reactor system, together with the front speed obtained from the temperature peak at each axial thermocouple. The schemes for the reaction process present at early and at end of the front propagation in the bed were found.

Charcoal was chosen as the base fuel due to the ease of interpretation of the data since it is the largest used and better known solid fuel. Were used for each experiment a particle size of 2 mm, a fuel mass of 0.6525 kg and two different air flow were tested: 0.676 kg/h and 0.151 kg/h.

To know the composition of charcoal used in the experiments was made a proximate and ultimate chemical analysis. Table 1 shows the results.

Table 1: Proximate and ultimate chemical analysis of charcoal (wt %).

| Moisture | Ash | C | H | O | N | S |
|---|---|---|---|---|---|---|
| 11.5 | 8.5 | 62.56 | 3.94 | 10.64 | 1.16 | 1.35 |

## 3. Results and discussion

Figure 1a shows the evolution of the mole fractions of O2 and CO2 in the flue gas. It can be seen that there is an interval during which CO2 values reach their maximum value (range 5000-10000 s) that corresponds to the time when the combustion front is passing over the system micro sampling. Figure 1b shows the front speed obtained from the temperature data along the bed. For the interval during which the front is passing through the micro-sampling system (observed by gas analysis) the speed of the front is about 1.3 mm/min. Thus, as the front delay 5000 sec (83.3 min) to pass through the micro-sampling system is obtained the length of the front (reaction zone): **10.83 cm**.

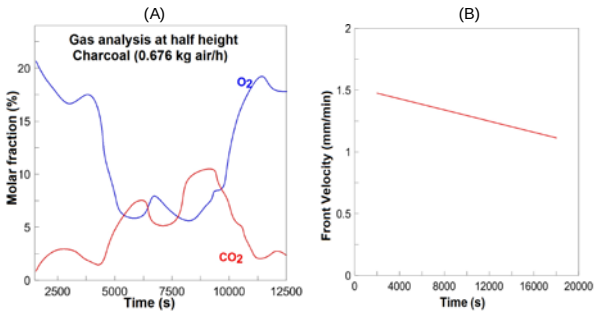


Figure 1: (A) Gas species evolution (processed data by successive weighted averages). (B) Front acceleration from temperature data.

Gas analyzes were carried out in the reactor at the beginning and end of the experiments. As shown in Figure 2a, two combustion schemes have been found in the reactor at different flow rates. Initially oxygen is completely consumed by the reactions that reach their limit due to the unavailability of more oxygen. In the final part of the experiment there is sufficient availability of oxygen in the reaction zone, however, the reactions have no ability to consume all the available oxygen. The highest concentration of CO2 to lower flows is due to lower flow velocity in the experiment allowing volatilized gases are achieved by the combustion front and are consumed forming more CO2. Therefore, it is possible to schematize the distribution of CO2 and O2 in the bed at the initial and final of the experiments, as shown in Figure 2b. The estimated length of the oxidation zone previously obtained was used to facilitate their viewing.

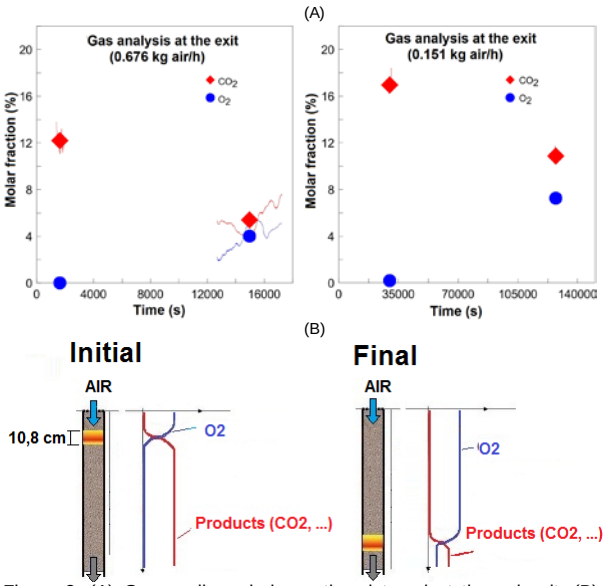


Figure 2: (A) Gas analisys during a time interval at the cel exit. (B) distribution of CO2 and O2 in the bed.

## 4. Conclusions

Through the use of gas evolution in time and with the front speed, a thermo-chemical structure, rather than a chemical structure, is defined. The length of the front was found to be 10.83 cm. It was found that oxygen limited combustion occurs initially and finally a reaction limited combustion. A distribution of CO2 and O2 gases through the reactor was then proposed. It is up to future studies to analyze in more detail the distribution of gas along the reactor to find out the moment at this change occurs.

## 5. References

[1] WANG JH; CHAO CYH; KONG W. Combustion and Flame v. 135 (4): p405-419, 2003.

[2] SHIN D; CHOI S. Combustion and Flame v. 121 (1-2): p167-180, 200.

[3] YANG YB *et al.* Fuel v. 83 p1553-1562, 2004.

[4] MARTINS M. F. The structure of a combustion front propagating in a fixed bed of crushed oil shale: co-current configuration. Ph.D. thesis, University of Toulouse, Toulouse, 2008.

[5] MONHOL *et al.* Advanced Materials Research, Issue 911, p373-377. 5p, 2014.