24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-1271
FLUIDIZED BED COMBUSTION OF CHAR PELLETS MADE FROM BLENDS OF SHRUBS AND CORK RESIDUES

E. Marques
Polytechnic of Viseu, School of Technology and Management, Viseu, Portugal
edmundo.marques@gmail.com
T. Ferreira
CEFT-DEMEC Faculdade de Engenharia da Universidade do Porto, Porto, Portugal
tania_vanessa@hotmail.com

C. Pereira
Polytechnic of Viseu, School of Technology and Management, Viseu, Portugal
ccatorze@ipv.pt

C. Pinho
CEFT-DEMEC Faculdade de Engenharia da Universidade do Porto, Porto, Portugal
ctp@fe.up.pt

J. Paiva
Polytechnic of Viseu, School of Technology and Management, Viseu, Portugal
jmonney@demgi.estv.ipv.pt

Abstract. *Industrial pellets made from blends of shrubs and cork residues were made in lab facilities and tested under the European standards for solid biofuels (ENPlus). The pellets were carbonized in nitrogen atmospheres at 800 °C, being subsequently cut into smaller and more uniform particles. Three different lengths, 4-5, 7-8 and 11-12 mm were used. The mean diameter of the char pellets was determined using the Image J open source image processing program software. The combustion tests were carried out in a fluidized bed reactor at two different temperatures, 700 and 800 °C. Using a simple combustion model of Pinho, et al. (2015) kinetic and diffusive data, namely* k_c *and Sh values, were obtained.*

Keywords: *Pellet blends, combustion, fluidized bed, diffusive and kinetic data.*

1. INTRODUCTION

The technologies of the Portuguese cork industry are highly energy dependent; and at cork processing, some of by-products have high energy value. Pelletized biofuels from waste with improvements in combustion technologies can be a way to reduce environmental impacts and overcome energy deficiencies.

The experimental data obtained in the combustion of the biochar pellets were analyzed using a mathematical model for combustion of solid carbon particles in a bubbling fluidized bed reactor (Rangel and Pinho, 2010; Pereira and Pinho, 2014). This model was based on the two phase theory of fluidization (Davidson and Harrison, 1963) and it was assumed that the solid particles are spherical and burn at a constant density and reducing size. It was also considered that the particle carbon burns to CO according to $C + ½\, O_2 \rightarrow CO$ and the CO formed burns away from the particle according to $CO + ½\, O_2 \rightarrow CO_2$ (Ross and Davidson, 1982).

For this model, the oxygen consumption rate at the surface of the particle is then half the carbon consumption rate and the heterogeneous phase reaction that takes place at the particle surface is a first order reaction,

$$N_{O_2} = \frac{1}{2} R_0 = \pi d \mathrm{Sh} D_G (c_p - c_s) = \frac{1}{2} k_c \pi d^2 c_s \tag{1}$$

where N_{O_2} is the molar oxygen flow rate reaching the particle surface, R_0 is the carbon consumption rate, *Sh* is the particle Sherwood number, d is the diameter of the burning particle, D_G is the oxygen diffusivity in the air, c_p e c_s are respectively the molar concentrations of oxygen in the bed dense phase and at the surface of the particle, and k_c is the reaction rate constant for the heterogeneous reaction. Manipulating the above equation, it is possible to write that:

$$R_0 = 2\,\pi K d^2 c_p \tag{2}$$

wherein,

$$\frac{1}{K} = \frac{2}{k_c} + \frac{d}{Sh\,D_G} \tag{3}$$

Looking at the above equation it is apparent that the relationship between the global resistance to the combustion reaction of a single particle $1/K$ and the diameter, is linear, where the slope of the straight line depends on the Sherwood number Sh, and the oxygen diffusivity D_G, while the intercept depends on the reaction rate constant k_c. Based on the adopted mathematical model and according to Eq. (3), diffusive and kinetic data for the fluidization bed combustion of a carbon particle were obtained through the plotting of $1/K$ versus d, the particle diameter. To obtain the necessary information for the experimental determination of the overall resistance to the combustion reaction of a single particle, it is necessary to analyze the combustion of batches of particles through the evolution of the composition of the exhaust gases, in particular the CO_2 concentration.

2. EXPERIMENTAL PROCEDURE

Pellets with 6 mm diameter of Cytisus mixed with cork residues were made in a pelleting press. For 30 minutes, batches of 300 g of pellets were then carbonized in a fixed bed at 800 °C in a nitrogen atmosphere. The resulting char pellets were cut into smaller and uniform particles with lengths between 4-5, 7-8, and 11-12 mm. Theirs equivalent diameters, sphericity and the Sauter mean diameter, were determined with its digital photographs and using the image J software, Fig. 1.

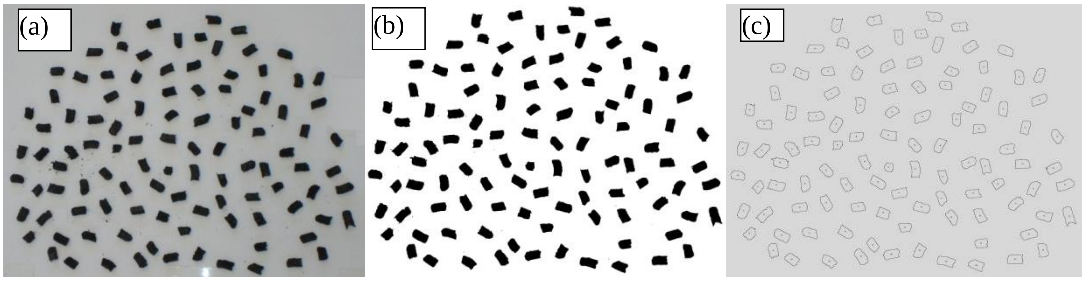

Figure 1: Digital photograph of 7-8 mm char pellets (a) Image analysis with program ImageJ (b) and (c)

The char proximate analysis was performed at IPV – Polytechnic of Viseu lab facilities and its density was determined by mercury porosimetry technique at FEUP - Faculty of Engineering of the University of Oporto. Table 1 presents the main properties of the tested char pellets.

Table 1: Properties of char pellets

	Cytisus and cork residues 50% (m/m)
Apparent density (kg/m^3)	858.3
Volatile matter (%)	8.6
Fixed carbon (%)	77.0
Ashes (%)	14.4

The burning tests were carried out in the facilities referred to in previous works (Pereira, *et al.*, 2013; Pinho, *et al.*, 2014), Fig. 2. Batches of 6 g of char pellets were burned at two different temperatures 700 and 900 °C using three average equivalent particle diameters: 4.5, 7.5 and 11.5 mm. The mass flow rate of the supplied air to the combustor was of $2U_{mf}$ and the CO_2 concentration was continuously measured by an ADC 7000 infrared analyzer.

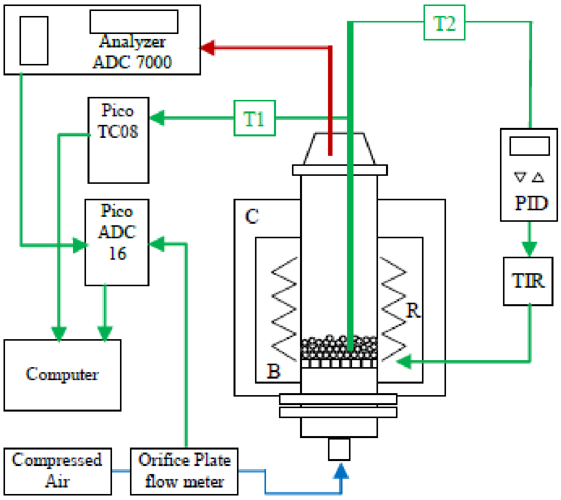

Figure 2: Experimental set-up: T1 and T2 – Thermocouples; PID – Proportional, integral and derivative controller; TIR – Thyristor; C - Kaowool ceramic blanket; B – refractory bricks; R – electrical resistor.

3. RESULTS AND DISCUSSION

Using the experimental data collected in the fluidized bed combustion of char pellets and the mathematicall model mentioned above, the overall combustion resistance was determined at every instant.

Figure 3 shows the evolution of the overall combustion resistance for char pellets made of shrub and cork residues with 4.85 mm equivalent diameter at 700 and 800 °C.

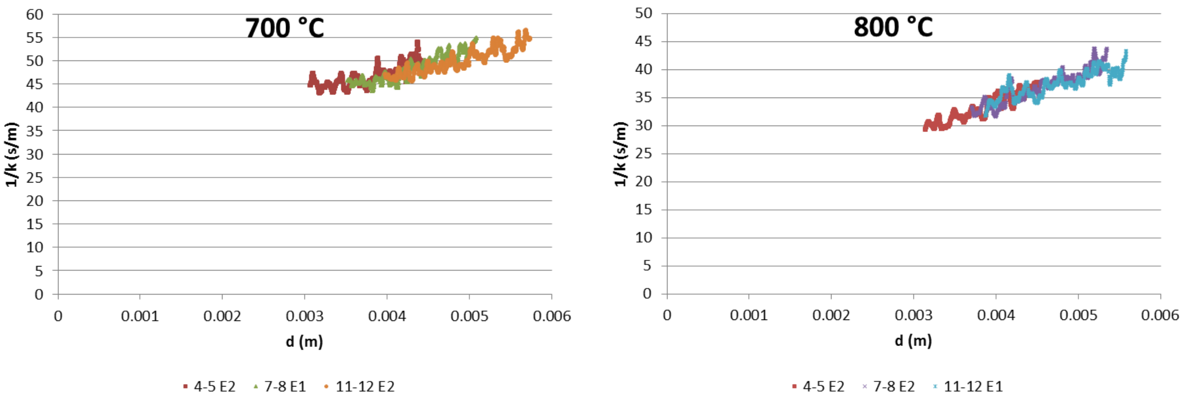

Figure 3: Overall combustion resistance as function of particle diameter at 700 and 800 °C.

Table 2 presents the Sherwood numbers and kinetic constants obtained from the analysis of Figure 3.

Table 2: Diffusive and kinetic data

	d_{eq} (mm)	Sh	k_c
Test 1, 700 °C, 4-5 E2	4.87	1.812	0.067
Test 2, 800 °C, 4-5 E2	4.99	1.251	0.170
Test 3, 700 °C, 7-8 E1	5.60	1.370	0.087
Test 4, 800 °C, 7-8 E2	5.89	1.230	0.182
Test 5, 700 °C, 11-12 E2	6.32	1.738	0.073
Test 6, 800 °C, 11-12 E1	6.15	1.817	0.104

4. CONCLUSIONS

The combustion of char pellets made of shrub and cork residues was studied in a bubling fluidized bed. Diffusive and kinetic data were obtained at two different temperatures, 700 and 800 °C for three diferent equivalent diameters. As expected, the results show that the overall combustion resistance decreases with the increase of the bed temperature and the heterogeneous reaction rate constant increases.

5. REFERENCES

Davidson, J.F. and Harrison, D., 1963. *Fluidized particles*. Cambridge University Press.

Pereira, C., Marques E., Paiva J.M., Pinho, C., 2013. "*Cistus Ladanifer* shrub – Some combustion data from pelletized samples: A small contribution to energy sustainability". In *Proceedings of 22nd International Congress of Mechanical Engineering - COBEM 2013*. Ribeirão Preto, SP, Brazil.

Pereira, C.C. and Pinho, C., 2014. "Influence of particle fragmentation and non-sphericity on the determination of diffusive and kinetic fluidized bed biochar combustion data". *Fuel*, Vol.131, p. 77-88.

Pinho, C., Ferreira T., Marques E., Almeida D., Pereira C. and Paiva J.M., 20015."Steady state fixed bed combustion of wood pellets. A simple theoretical model". *Thermal Engineering*, Vol.13 (2), p. 59-66.

Pinho, C., Ferreira T., Marques E., Almeida D., Pereira C., Paiva J.M., 2014. "Obtaining diffusive and kinetic data from batch combustion of invasive species char pellets". In *Proceedings of 15th Brazilian Congress of Thermal Sciences and Engineering - ENCIT 2014*. Belém, PA, Brazil.

Rangel, N. and Pinho, C., 2010. "Fragmentation Effect on Batches of Pine Wood Char Burning in a Fluidized Bed". *Energy Fuels*, Vol.24, p. 318-323.

Ross, I.B. and Davidson, J.F., 1982. "The combustion of carbon particles in a fluidized bed". *Trans. IChemE*, Vol. 60, p. 108-114.

6. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.