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SLOW PYROLYSIS OF SOYBEAN STALK FOR ENERGY PURPOSES

Matheus Geovani Macedo Oliveira

Estela Mary Galvão

Felipe da Cunha Fagnani Boschi

Carlos Manuel Romero Luna

UNESP – São Paulo State University, Campus of Itapeva, Rua Geraldo Alckmin, 519, 18409-010, Itapeva-SP, Brazil.

matheus.gm.oliveira@unesp.br; estela.galvao@unesp.br; felipe.fagnani@unesp.br; carlos.romero-luna@unesp.br;

Diogo Garcia Nunes

Gretta Larisa Aurora Arce Ferruffino

UNESP – São Paulo State University, Guaratinguetá Engineering Faculty, Department of Energy, Combustion and Carbon Capture Laboratory (LC3), Av. Dr. Ariberto Pereira da Cunha, 333, 12.516-410, Guaratinguetá-SP, Brazil.

gretta.arce@unesp.br; diogo.nunes@unesp.br

Antonio Carlos Borelli Junior

Agrocete Indústria de Fertilizantes LTDA, Agrocete Agrospecialties US

antonio.borelli@agrocete.com

Abstract. *Biomass is a source of renewable energy. Biomass pyrolysis has gained prominence due to the potential to produce renewable, but also petrochemical, fuels; consequently, this can minimize dependence on fossil fuels. Soybean production generates a significant amount of waste which has the potential to be an energy source. Among these residues, the soybean stalks are found in a significant amount. In this study the slow pyrolysis of soybean stalks was realized in different temperatures using nitrogen as gas carrier. Combustion indices were used to evaluate the biochar as solid fuel. The results obtained in this study shows that the use of soybean stalks through slow pyrolysis is a potential alternative to produce second-generation biofuels. Biochar from soybean stalks shows solid fuel characteristics better than raw biomass.*

Keywords: *Slow pyrolysis, soybean stalk, biochar, energy*

1. INTRODUCTION

Biomass is the fourth source of energy in the world and has been found to be a potential source of renewable energy (Saidur et al., 2011; Tinwala et al., 2015; Kim et al., 2017). The use of biomass can be carried out through biochemical and thermochemical conversion processes. However, thermochemical conversion has received more attention due to its speed and greater efficiency when compared to biochemical conversion (Tripathi et al., 2016). Among all the thermochemical processes, biomass pyrolysis has gained prominence due to the potential to produce renewable, but also petrochemical, fuels; consequently, this can minimize dependence on fossil fuels (Demiral and Sensöz 2006; Kabir and Hameed 2017). Biomass pyrolysis is the thermal decomposition process in an inert medium which results in three products: a solid (biochar), a liquid (bio-oil) and a gas (pyrolytic gas) (Demiral and Sensöz 2006; Tripathi et al., 2016).

Currently, the United States ranks first in biodiesel production followed by Brazil and Germany. In Brazil, biodiesel production derives mainly from soybean production. The demand for biodiesel in Brazil is due to the increased demand for diesel, since in the Brazilian market each liter of diesel contains 10% biodiesel in its composition. Although Brazil has the potential to produce biodiesel from other biomasses, soy is still the main raw material in the biodiesel production chain (Cesar et al. 2019). Thus, due to the demand for biodiesel, there is a considerable amount of waste derived from soy production. According to Nogueira et al. (2000) it is estimated that for each hectare of soy produced about 3.0 to 4.0 tonnes are vegetable biomass residues, that is, remains of soybean culture. The use of residues generated by soybean production through pyrolysis can somehow reduce the negative effects caused to the environment (Giri et al. 2017).

The literature presents several works on the pyrolysis of soybean residues, which aim mainly at studying the yield and quality of bio-oil (Oliveira et al. 2015; Zhang et al. 2017), however, little is known about the biochar and pyrolytic gas produced (Toro-Trochez et al. 2019). However, there are few works that aim to use the residues from soybean production for energy generation. Boateng et al. (2010) studied the rapid pyrolysis of soybean straw to produce bio-oil and biochar. The results showed that it is possible to produce a considerable fraction of bio-oil (77% mass yield), the

biochar (22% mass yield) and the pyrolytic gas reached up to 10%. Toro-Trochez et al. (2019) evaluated soybean hulls as an alternative source for obtaining biofuels and by-products through pyrolysis. The authors used thermogravimetric analysis techniques to study the behavior of pyrolysis at different temperatures. The results showed that the maximum yield obtained for bio-oil and pyrolytic gas was about 40% and 36% respectively at 600 °C. From the literature review, it was observed that the studies on pyrolysis of soybean residues aim at the study of obtaining bio-oil, however, there is a lack of work on the pyrolysis of soybean stalks to obtain biochar and bio-oil.

2. MATERIALS AND METHODS

2.1 Soybean stalks

In this study the soybean stalks were supplied by Holambra installed in Taquarivai-SP (Fig 1a). Soybean stalks were milled (Fig 1b) and for experimental teste a particle size between 250 – 500 µm was used.



Figure 1- Soybean stalks samples (a) raw; (b) particle size on range of 250 - 500µm.

2.2 Experimental setup

Figure 2 shows the experimental setup used for pyrolysis test. For experimental test was considered a temperature of 300°C; 400°C and 500°C. The reaction time was 30 min for all tests, considering the process temperature has stabilized. In all experiments the mass of biomass was 30g. A gas flow of 100ml/min of nitrogen is used to carrier the material volatile. HHV was determined using a Calorimeter IKA C500. All tests are performed in duplicate using a mass of (0.5 ± 0.05) g. A pH meter model 522 of MS Tecnopon equipment was used to determine the pH of the samples.

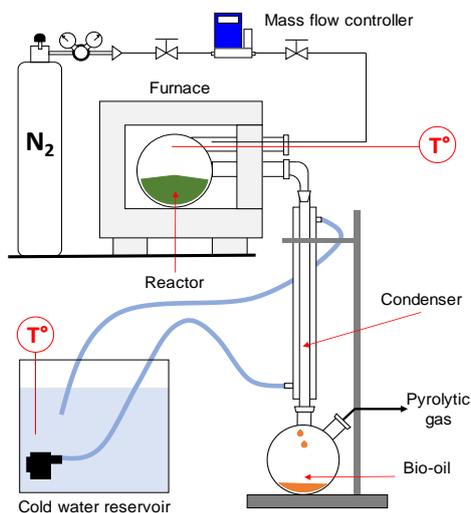


Figure 2 – Experimental setup of slow pyrolysis.

2.3 Combustion indices

To estimate the usefulness of soybean stalk and biochars as solid fuel, some combustion indices are usually used as fuel ratio, combustibility index and volatile ignitability. Combustion indices were calculated using Eqs. 1 – 3 as mentioned by Conag et al. (2017). Fuels having FR values ranging from 0.5 – 2.0 are commonly used in coal-fired power plants. Ignition and flame stability problems are encountered with fuels having FR values > 2.0. For the CI, it is recommended to have a value of 23 MJ/kg. For the VI, it is recommended that at the minimum, the volatile matter should have a specific HHV of at least 14MJ/kg (Conag et al. 2017; Conag et al. 2018).

$$\text{Fuel ratio, } FR = \frac{FC_{db}}{VM_{db}} \quad (1)$$

$$\text{Combustibility Index, } CI \text{ (MJ/Kg)} = \frac{HHV_{db}}{FR} \times (115 - Ash_{db}) \times \frac{1}{105} \quad (2)$$

$$\text{Volatile Ignitability, } VI \text{ (MJ/Kg)} = \left[\frac{HHV_{db} - 0.338FC_{db}}{VM_{db} + M_{db}} \right] \times 100 \quad (3)$$

3. RESULTS AND DISCUSSION

3.1 Products yield from slow pyrolysis, proximate composition and HHV

Figure 3 shows the products obtained from the slow pyrolysis of soybean stalks. Biochar (Fig. 3a) is the dark carbonaceous material due to the high concentration of carbon. In all tests, the biochar obtained had the same qualitative characteristics. The bio-oil (Fig. 3b) had a dark color and a strong smell derived from the volatile components present in its composition. The pyrolytic gas (Fig. 3c) obtained underwent a flammability check demonstrating that it contains combustible substances in its composition.

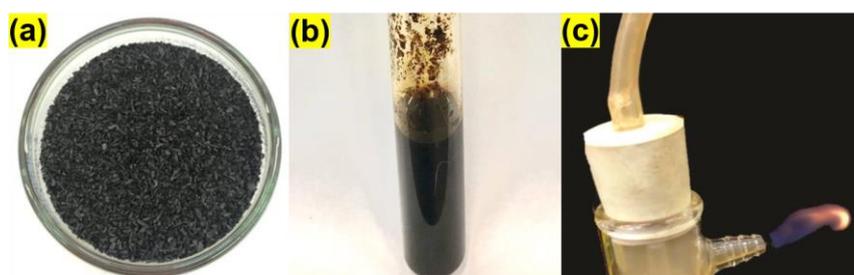


Figure 3 – Products from slow pyrolysis of soybean stalks (a) biochar; (b) Bio-oil and (c) Pyrolytic gas.

Table 1 shows the product yields from pyrolysis of soybean stalk (SS). It can be observed that as the pyrolysis temperature increases, the biochar yield decreases and the yields of bio-oil and pyrolytic gas increase proportionally. In all tests, a significant amount of bio-oil was produced, and pyrolytic gas yield increased with the pyrolysis temperature.

Table 1 – Product yields from slow pyrolysis of soybean stalks.

| Temperature (°C) | Yield (%) | | |
|------------------|-----------|---------|---------------|
| | Biochar | Bio-oil | Pyrolytic gas |
| 300 | 33,86 | 45,12 | 21,02 |
| 400 | 28,36 | 47,43 | 24,11 |
| 500 | 26,36 | 47,28 | 26,36 |

Table 2 shows the proximate composition of SS and biochar obtained at 300°C (B300); 400°C (B400) e 500°C (B500) respectively. The SS has a significant amount of volatile material, which would make it easier to ignite. As the pyrolysis temperature increases, there is a considerable reduction in the content of volatile material and a progressive increase in the levels of fixed carbon and ash. The B400 exhibits almost similar amounts of fixed carbon and volatile material, this is important because the amount of volatile material cannot be reduced much as it would cause ignition difficulties, requiring a greater activation energy to cause its combustion. An increase in the moisture content is observed in the obtained biochar, which is a result of the pyrolysis temperature, and at higher temperature the decomposition of the biomass components is higher, resulting in a greater water formation, however, most ends present in the composition of the bio-oil.

Table 2 – Proximate composition of soybean stalk and biochar (dry basis)

| Material | MC | FC | VM | Ash |
|----------|------|-------|-------|------|
| SS | 6,2 | 8,55 | 89,52 | 1,91 |
| B300 | 0,1 | 31,97 | 61,83 | 6,2 |
| B400 | 0,61 | 47,28 | 45,90 | 6,81 |
| B500 | 3,08 | 58,76 | 34,05 | 7,18 |

Table 3 shows the HHV of biochar and bio-oil. The results show that the HHV of biochars are higher than the HHV of raw soybean stalk (17,36 MJ/kg - dry basis) having an increase of up 65%. The HHV of biochars increases proportionally with the temperature, however, at 400 °C little changes in the value were observed. This result suggests that 400 °C is a suitable temperature for slow pyrolysis. However, the HHV of bio-oil obtained at different temperatures has a lower value when compared to raw soybean stalk. The HHV value of bio-oil has low values, this may be due to the presence of water in its composition, and an increase in temperature causes a greater decomposition of the biomass resulting in greater water formation, this characteristic can limit their application. This can be correlated with the increased moisture content in the B500. An alternative to take advantage of the bio-oil and pyrolytic gas produced in order to reduce costs, would be to use these pyrolysis products as fuels in the production of biochar, this could make the process thermally self-sustainable.

Table 3 – High Heating Value of biochar and bio-oil.

| Temperature (°C) | HHV Biochar* MJ/kg | HHV Bio-oil MJ/kg |
|------------------|--------------------|-------------------|
| 300 | 24,47 | 6,66 |
| 400 | 27,24 | 6,03 |
| 500 | 28,65 | 5,41 |

*HHV in dry basis

3.3 Combustion indices of biochar

Table 4 shows the results of combustion indices. Biochars from soybean stalks were determined to have a FR ranging from 0.52 to 1.73, while CI from 22,06 MJ/kg to 23,67MJ/kg, and VI from 17 MJ/kg to as much as 49 MJ/kg. The pyrolysis temperature has an influence on the FR and CI values; however, it does not have a significant effect on the VI values. According to the FR values obtained for the soybean stalk, it presents a value lower than the limit, this means that directly using the soybean stalk to produce thermal energy would have a serious difficulty.

For soybean stalk, pyrolysis at a temperature of 500°C is sufficient to meet all three combustion indices, however, pyrolysis in high temperature it demands a greater amount of energy, so the biochar obtained at 400°C can also be an option even with the CI slightly outside the established range. With the purpose of satisfying all combustion indices, the optimum temperature would be between 400°C and 500 °C. According to Adeleke et al., (2020) a low FR usually results in more flaming combustions, less char combustion, and quicker burnout. An increase of FR will enable a stable and lasting combustion process, especially when used in a boiler. The VI of biochars were better than those of raw soybean stalks and it increases with pyrolysis temperature, however, it reaches a maximum value at 400 °C. Adeleke et al. (2020) have reported that a high FR significantly points to a high VI.

The use of biochar as a fuel instead of raw soybean stalk has some benefits, since combustion would be more stable and cleaner in terms of emissions, the possibility of being mixed with other fuels, significantly reducing the volume and cost of treating exhaust gases. In addition, the biochar can be stored as it has no effect on the organic decomposition of the material.

Table 4 – Combustion indices.

| Material | FR - | CI MJ/kg | VI MJ/kg |
|----------|------|----------|----------|
| SS | 0,10 | 196 | 15,12 |
| B300 | 0,52 | 49 | 22,06 |
| B400 | 1,03 | 27 | 24,21 |
| B500 | 1,73 | 17 | 23,67 |

4. CONCLUSIONS

In this work, it was demonstrated that slow pyrolysis of soybean stalk has the potential to produce biofuels. The soybean stalk burned directly to generate thermal energy would present some difficulties. The biochar obtained at 400 °C satisfies all combustion indices, however, studies on temperature optimization are necessary. The use of combustion indices allows a more detailed assessment to be made to assess the potential that a biomass has as a fuel for thermal energy generation, than when using only the heating power as a reference.

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