CO_2 gasification of elephant grass in a fixed bed reactor

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Abstract

In order to supply the growing world demand of energy and relieve the global warming, biomass is considered a potential clean energy source. In this work, the thermochemical conversion of the elephant grass, through CO_2 gasification, for the production of a combustible gas was evaluated. The gasification experiment was conducted at the temperature of 900 °C for 90 min under a carbon dioxide atmosphere. CO presented a maximum production rate of 2.25 mmol/min.$g_{biomass}$ and a maximum concentration of 82 %mol/mol. The fuel gas produced had an average high heating value of 8.5 MJ/Nm³. Considerable hydrogen production rates were observed throughout the experiment. The experiment had an energy yield of 28.4 kJ/$g_{biomassa}$. The results showed that CO_2 gasification of elephant grass has the potential to produce a combustible gas allowing the reduction of CO_2 emissions to the atmosphere.

Keywords: CO_2 gasification. Elephant grass. Renewable energy.

Theme Area: Energy and renewable energies.

Gaseificação de capim elefante com CO_2 em um reator de leito fixo

Resumo

A fim de suprir a crescente demanda energética mundial e reduzir o aquecimento global, a biomassa é considerada uma fonte potencial de energia limpa. Neste trabalho, avaliou-se a conversão termoquímica do capim-elefante, através da gaseificação com CO_2, para a produção de um gás combustível. O experimento de gaseificação foi conduzido na temperatura de 900 °C durante 90 min sob uma atmosfera de dióxido de carbono. O CO apresentou uma taxa de produção máxima de 2,25 mmol/min.$g_{biomassa}$ e uma concentração máxima de 82% mol/mol. O gás combustível produzido apresentou um poder calorífico superior médio de 8,5 MJ/Nm³. Foram observadas taxas de produção de hidrogênio consideráveis ao longo de todo o experimento. O experimento apresentou um rendimento energético de 28,4 kJ/$g_{biomassa}$. Os resultados obtidos mostraram que a gaseificação de capim elefante com CO_2 possui potencial para a produção de um gás combustível, permitindo a redução das emissões de CO_2 para a atmosfera.

Palavras-chave: Gaseificação com CO_2. Capim elefante. Energia renovável.

Área Temática: Energia e energias renováveis.

1 Introduction

The explosive increasing energy consumption is one of the critical challenges throughout the world, and currently significant percentage of the consumed energy comes from fossil fuels, such as petroleum, coal and natural gas (CHENG; THOW; WANG, 2016). According to Kirkels and Verbong (2011), the search for a reliable, affordable and clean energy supply will prove to be crucial in the 21st century. In this context, the potential of biomass to help to meet the world energy demand has been widely recognized (KIRUBAKARAN et al., 2009). By deriving more energy from biomass feedstock, countries with high biomass production capacity (e.g. Brazil) will be able to significantly decrease their reliance on foreign fossil fuels. Biomass is a CO_2 neutral and environmentally friendly energy source, as it is formed by the plant photosynthesis process, which absorbs CO_2 from the atmosphere (CHENG; THOW; WANG, 2016).

Although the first generation biofuels can offer some CO_2 benefits, there are concerns about the impact it may have on biodiversity and competition with food crops (NAIK et al., 2010). Second generation biofuels can be grouped into biochemically or thermochemically produced, either route using nonfood crops, purpose-grown perennial grasses, trees or residues (GÜELL; SANDQUIST; SØRUM, 2011). Combustion, pyrolysis and gasification are three main thermochemical conversion methods. According to Asadullah (2014), gasification is one of the most promising technologies to exploit energy from renewable biomass. Gasification converts biomass through partial oxidation into a gaseous mixture of syngas consisting of hydrogen (H_2), carbon monoxide (CO), methane (CH_4) and carbon dioxide (CO_2) (WANG et al., 2008). As carbon emissions become increasingly regulated, gasification based technologies are benefited from its characteristics to offer increased efficiency and allow for carbon capture and storage (KIRKELS; VERBONG, 2011). In this context, the modern use of biomass (as opposed to the traditional combustion) is considering very promising (KIRKELS; VERBONG, 2011; SÁNCHES, 2010). Furthermore, the use of CO_2 as gasifying agent in gasification processes provides a reliable and long-term alternative to mitigate the accumulation of CO_2 in the atmosphere and allows for production of clean fuels (LAHIJANI et al., 2015).

Elephant grass (*Pennisetum purpureum Schum*) is a perennial grass of the Poaceae family, which is a promising source of renewable energy due to its fast growth (can be harvested up to four times a year), disease resistance, easy adaptability and can grow on different types of soils (FERREIRA et al., 2017). Even though most of works in biomass gasification has been performed on wood, according to Mohan, Pittman and Steele (2006), nearly 100 types of biomass have been already tested, ranging from agricultural wastes to energy crops. Despite the numerous papers published, biomass gasification with CO_2 as gasifying agent is seldom addressed (CHENG; THOW; WANG, 2016). Therefore, the objective of the present study was to evaluate the gasification of elephant grass with CO_2 and to perform the characterization of the fuel gas produced.

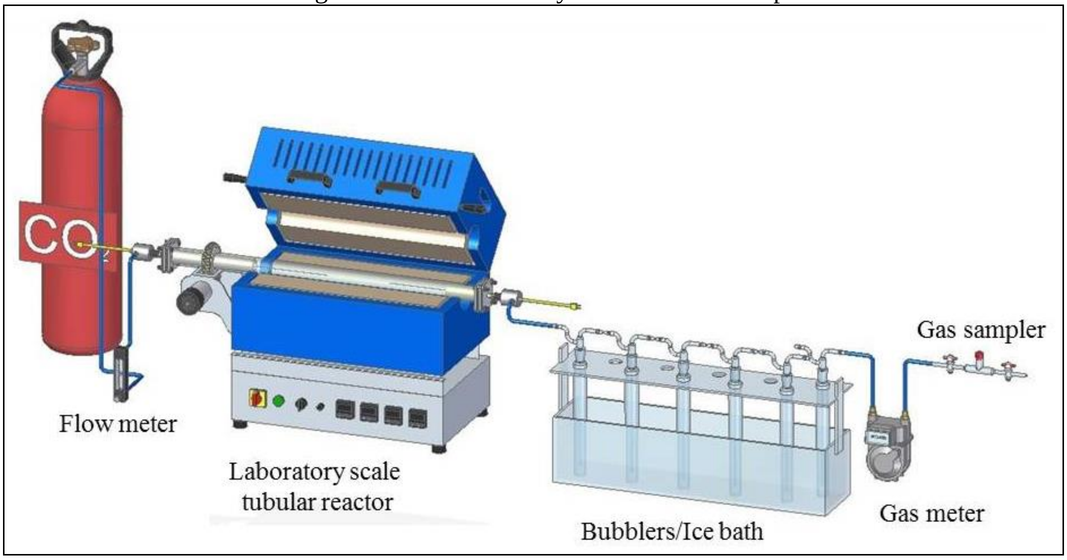
2 Experimental

The elephant grass used in the gasification experiments was planted in a rural unit of the University of Caxias do Sul. The biomass was milled in a knife mill and sieved to select the granulometry in between 425 and 841 µm, suitable for the gasification experiment. Prior to the experiment, the sample was dried in an oven at 105 °C for 10 h.

In this work, the elephant grass gasification was conducted with 20 g of sample in a laboratory scale tubular reactor which operates in batch system. The reactor is heated by two electrical resistances and the temperature is measured by two type K thermocouples positioned inside the reactor. Figure 1 presents the gasification system used in the experiment.

A complete description of the reactor was given by Perondi et al. (2017). Initially, the furnace was heated until the final temperature of 900 °C. After reaching the desired temperature, the CO_2 flow rate was set at 0.5 NL/min, the tubular reactor was inserted into the hot furnace and the gasification experiment was started.

Figure 1 – Gasification system used in the experiment

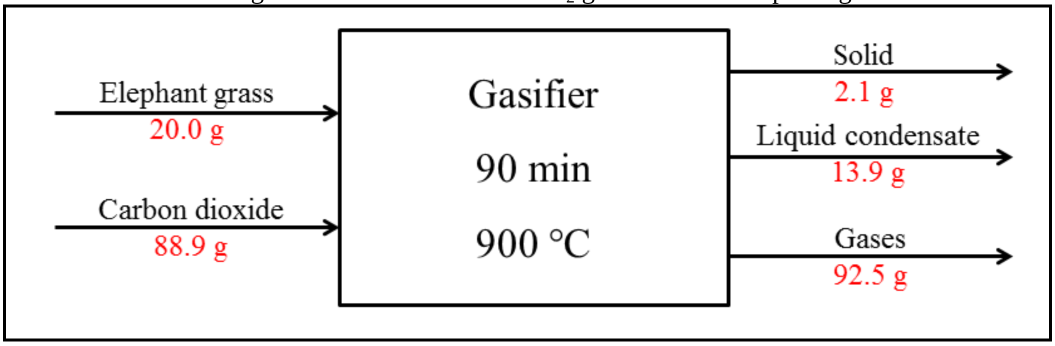


The removal of the condensable vapors was conducted with six bubblers. In each one, 100 mL of isopropyl alcohol was added, with the exception of the first and last bubbler which remained empty. All the bubblers were placed in an ice-bath in order to keep them under low temperature. The non-condensable gases were collected at intervals (3, 6, 9, 12, 15, 20, 25, 30, 45, 60, 75 and 90 min) and were analyzed by using a gas chromatograph Dani Master GC. The gases analyzed were H_2, CO, CO_2 and light hydrocarbons ($<C_5$). The non-condensable gases volume was measured with a diaphragm type gas meter with capacity to measure flow rates in the range of 0.27 to 27 L/min. At the end of the gasification experiment, the reactor was cooled to room temperature and the remaining solid was collected.

3 Results and Discussion

The mass balance for CO_2 gasification of elephant grass at 900 °C is presented in Figure 2. The overall mass balance achieved was 99 %. According to De Conto et al. (2016), the elephant grass presents an ash content of 8.3 wt.%. Thus, based on the solid yield (10.5 wt.%) it can be concluded the process was conducted until almost complete conversion of the biomass.

Figure 2 - Mass balance for CO_2 gasification of elephant grass



The concentration of non-condensable gases produced in the gasification experiment is shown in Figure 3. As can be seen from the figure, some time is needed for the system to achieve the stabilization. This behavior is mainly due to the initial heating of biomass until the working temperature of 900 °C. The CO concentration in the gas increased continuously until 9 min and then it remained in a value of approximately 80 %mol/mol during the time interval of 9 - 30 min. Similarly, CO_2 presented a stable concentration of 10 %mol/mol in the same range. The composition gas profile described supports the occurrence of Boudouard reaction (Reaction 1), responsible for the high concentration of CO in the non-condensable gases. Moreover, according to Pohořelý et al. (2014), the Boudouard reaction presents a very slow kinetic, and this characteristic was responsible for the slow consumption of carbon in the solid resulting in the constant CO and CO_2 concentration profile observed in the time interval of 9 - 30 min in Figure 3.

$$C + CO_2 \rightleftharpoons 2CO \qquad \text{(Reaction 1)}$$

Figure 3 - Molar fraction of non-condensable gases produced in the gasification experiment.

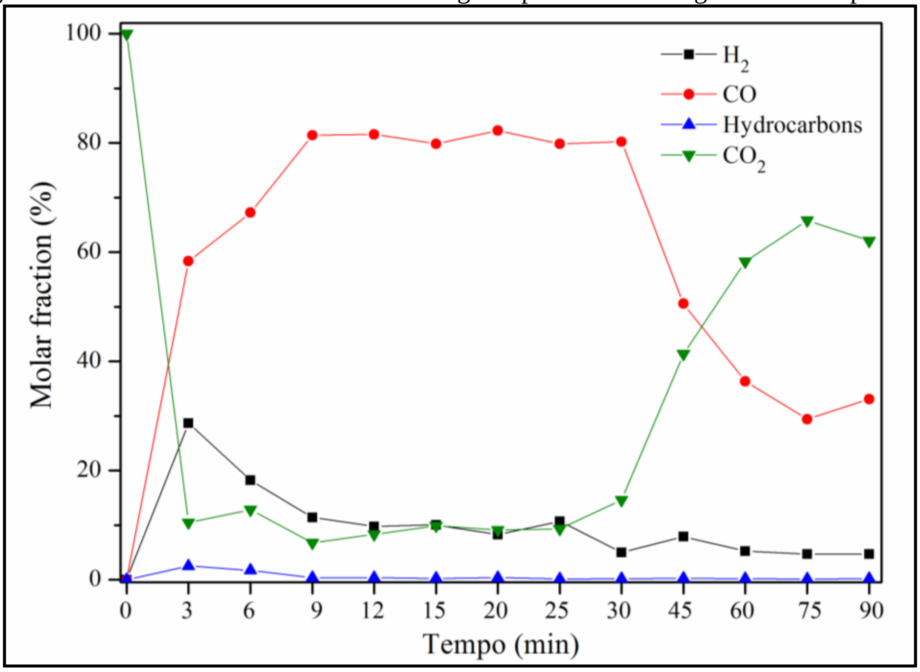
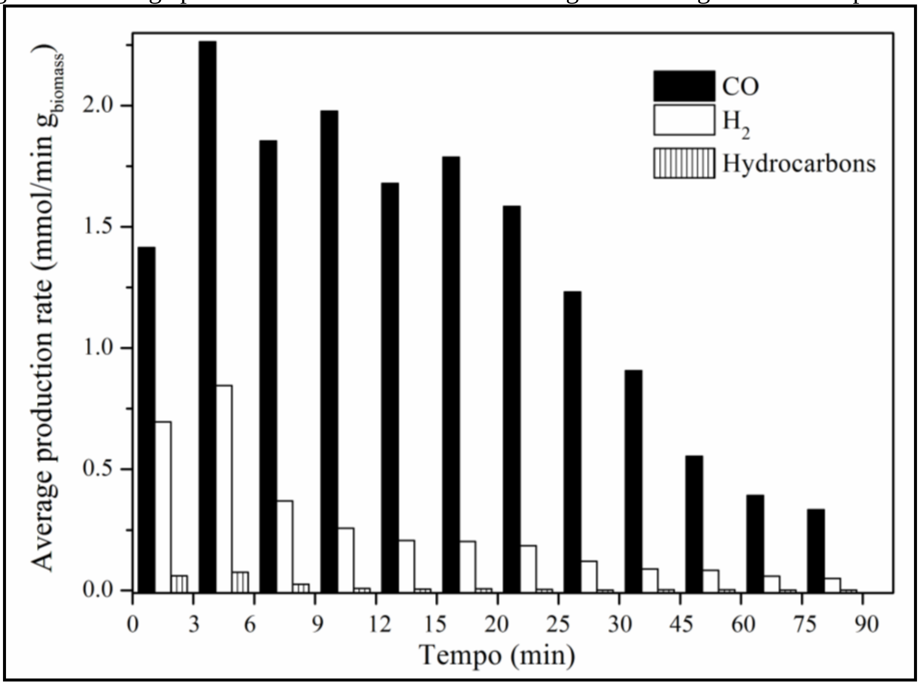


Figure 4 shows the average gas production rate (H_2/CO/hydrocarbons) at different intervals of time throughout the experiment. Since the gasification was conducted with CO_2 as gasifying agent, it is dificut to classify the CO_2 at the output as being generated by the gasification reactions or just as the unreacted portion of the input stream. Therefore, the CO_2 average production rate was not reported in the graphic. After the initial transitional stage, the higher gas production rates were obtained. The CO achieved the maximum production rate of 2.25 mmol/min.$g_{biomass}$ and then decreased continuously over time. The maximum production rate observed in the initial stage is due to the cooperation of the initial devolatilization of organic mater and the high concentration of carbon in the remaining solid material. The continuously reduction of carbon content in the solid material throughout the experiment caused the expected reduction of CO production rate.

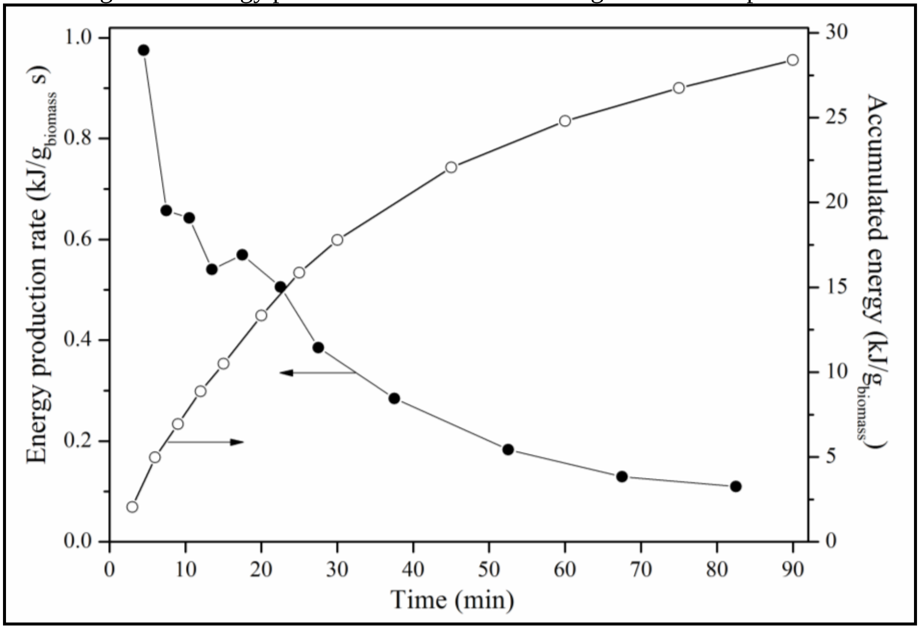
Although H_2 concentration kept reasonably constant during the experiment (Figure 3), the continuous reduction in the volume of gas produced caused the decrease in H_2 production rate observed in Figure 4. Taking into account the energy contained in the fuel gas, the gasification presented an energetic yield of 28.4 kJ/$g_{biomass}$.

Figure 4 - Average production rate of non-condensable gases in the gasification experiment



Since the higher gas production rates were obtained in the initial stage of the experiment, this stage is responsible for most of the energy produced. Figure 5 shows the accumulated energy produced as well as the contribution of the gas produced along the experiment in the total energy production. It can be seen from the figure that about 50 % of the energy was produced in the first 20 min. Furthermore, as the CO is the main combustible component contained in the non-condensable gas, the energy production rate profile presented in Figure 5 is very similar to the CO average production rate shown in Figure 4.

Figure 5 - Energy production versus time in the gasification experiment



4 Conclusions

The fuel gas produced in the CO_2 gasification of elephant grass presented a high CO concentration and it had an average high heating value of 8.5 MJ/Nm³. The results showed a high rate of carbon monoxide production, achieving the maximum value of 2.25 mmol/min.$g_{biomass}$. Considerable hydrogen production rates were observed throughout the experiment. The gasification of elephant grass presented an energetic yield of 28.4 kJ/g. Finally, the results presented shows that the CO_2 gasification of elephant grass represent a promising alternative to mitigate the accumulation of CO_2 in the atmosphere and for the production of a fuel gas.

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