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A statistical analysis of the auto thermal fast pyrolysis of elephant grass in fluidized bed reactor based on produced charcoal

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HIGHLIGHTS

- Pyrolysis of elephant grass was studied in a fluidized bed reactor.
- The product yields were evaluated.
- The composition of the solid products obtained was analyzed.
- The influence of three variables was studied statistically.

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ABSTRACT

This research presents and discusses the results of product yields, higher heating value, proximate and ultimate analyses of the charcoal obtained in the Fast Pyrolysis Plant – PPR-200. It is a fast pyrolysis plant with a biomass feed capacity of 200 kg per hour, owned by Unicamp. Elephant grass with an average particle diameter of 2 mm and 12% of moisture was used as raw material. The PPR-200 facility operated under different conditions. Air was used as fluidization agent. This study tries to increase the knowledge of the PPR-200 plant operation in fast pyrolysis regimen. Experimental tests were carried out considering two independent factors: fluidization air and stoichiometric air ratio and the height of the fixed bed. In the pyrolysis process, a charcoal with a high carbon content is obtained as well as the release of oxygen from the biomass. Experimental results showed that the favorable operating conditions for oxygen release from elephant grass and carbon concentration in the charcoal are a fixed fluidized bed of 207 mm height and 8% of supplied air to the stoichiometric air ratio. Under these optimized conditions, the fluidized bed temperature resulted to be 650 °C on average and the yield production of charcoal in relation to the biomass fed (dry and ash free, d.a.f.) was of 14 wt.%. The charcoal produced under such conditions presented 92.4% of elemental carbon, and 2.85% of elemental oxygen.

1. Introduction

The lignocellulosic biomass is a natural complex carbohydrate polymer mixture of cellulose, hemicellulose, and lignin, as well as small amounts of other substances, such as extractives and ashes, which are contained in the plant cellular wall. The biomass composition plays an important role in the pyrolysis product distribution. Under pyrolysis conditions each material presents unique characteristics due to their component ratios. Elephant grass is a potential biomass to feed thermochemical conversion processes such as fast pyrolysis [1].

Studies related to the reactor operation effects on the pyrolysis composition and distribution products, using response surface techniques are a great source of information for the work done in pilot scale. This is due to the lack of information on heat transfer mechanisms, mass and chemical reaction kinetics that control the biomass pyrolysis in fluidized beds. Problems such as unstable

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Nomenclature

ρ_f	density of the fluidization agent, kg m^{-3}
Ar	number of Archimedes
C	elemental carbon in charcoal, % (dry basis)
CF	fixed carbon in charcoal, % (dry basis)
C_z	ash content in charcoal, % (dry basis)
dp	particle diameter, mm
dp_b	biomass particle diameter, mm
dp_{ca}	charcoal particle average diameter, mm
dp_I	fluidized bed inert particle diameter, mm
H_L	height of the fixed bed, mm
H_{Lc}	height of the codified fixed bed
H_{Lf}	height of the fluidized bed, mm
H_{Lmf}	height of the fluidized bed in the minimum fluidization velocity, mm
k	number of independent factors
H	elemental hydrogen in charcoal, % (dry basis)
N	elemental nitrogen in charcoal, % (dry basis)
O	elemental oxygen in charcoal, % (dry basis)
p	probability to get values of Fisher F equal or bigger than F value. It can also be interpreted as the real value of the significance coefficient, α
Pae	fluidization air and stoichiometric air ratio, %
$Paec$	fluidization air and stoichiometric air ratio (codified), %
HHV	higher heating value, dry basis, MJ kg^{-1}
PFE	percentage of elutriates particles from the reactor, %
R^2	determination coefficient of the mathematical model
TML	fluidized bed average temperature, °C
V	volatile matter in charcoal, % (dry basis)
U	moisture in biomass (wet basis), %
u_0	gas superficial speed, m s^{-1}
μ_f	fluidization agent viscosity, Pa s
α	significance coefficient

profiles of the fluidized bed temperature, gas leaking through the feeding system, inert material sintering, reactor clogging, pressure fluctuations, etc, are frequent during the reactor operation and must be empirically solved [2].

Without losing the overall goal of the study is to optimize the bio-oil production, in order to investigate the characteristics of charcoal particles from elephant grass, experimental tests were set in a pilot plant PPR-200 under different operational conditions and using air as fluidization agent. For this research, an experimental design was carried out considering as independent variables fluidization air (related to the stoichiometric air ratio) and the height of the fixed bed. Proximate and ultimate analyses, charcoal yield and higher heating value were considered as response variables. Additionally, the temperature profiles in the reactor were measured.

Pyrolysis is a process to concentrate elemental carbon in solid charcoal and to release the oxygen in volatiles, therefore, as a hypothesis fast pyrolysis is considered an able process to concentrate elemental carbon in charcoal particles and release the oxygen from biomass. Finally, the designed experiment employing response surface methodology is valuable for scale-up and industrialization of the technology.

2. Experimental methodology

Pyrolysis in an endothermic process and in the experimental setup used, part of the organic matter (about 10%) combustion takes place in the fluid bed (lower part) to provide heat necessary for the thermal decomposition of biomass (in higher part of the bed). As resulting, char properties are the object of the study, the conclusions obtained are not general to other process where heat is supplied in a different way, for instance indirect heating. Fig. 1 shows the experimental facility installed at the University of Campinas (Unicamp), in Campinas, Brazil. The fast pyrolysis experiments in pilot scale are based on fluidized bed technology and use air as fluidization agent. The main components that comprise the plant are: biomass feeding system composed by transporting conveyor (1), silo (2), biomass feeder (3), feeding screw (4), fluidized bed reactor (5) with delivered air plate (6), 2 cyclones in series to separate the charcoal particles (7), sampler collector valves (8) with drums to store the charcoal (9), wet recovery system of charcoal (10), bio-oil recovery system (11) and flare (12).

The cylindrical reactor was built in carbon steel with inner diameter of 417 mm, and internally coated with refractory thermal insulation. Feeding capacity varies from 50 to 200 kg h^{-1} of dry biomass, particle size less than 1 mm, and a bed of inert material is

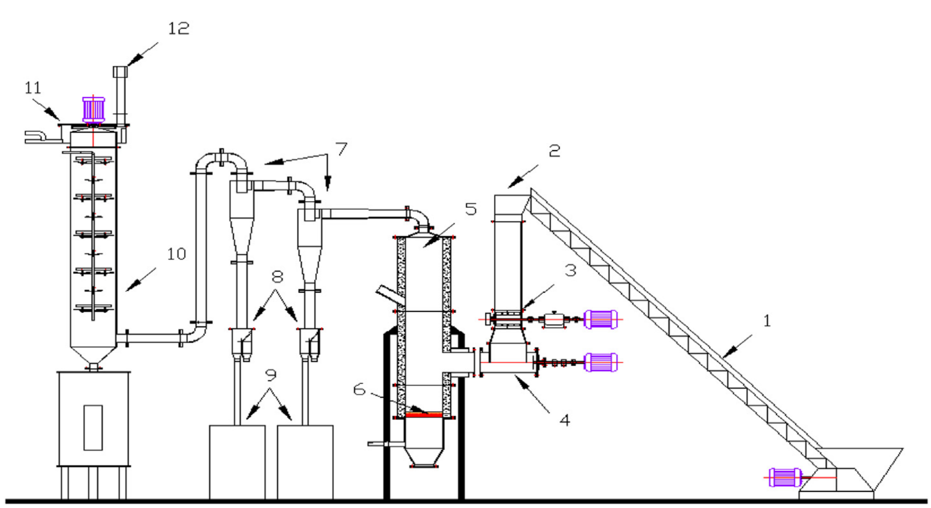

Fig. 1. PPR-200 fast pyrolysis facility scheme.