# Operating Conditions Affecting the Behavior of Wheat Straw Pellets During Slow Pyrolysis Process: a Full Insight

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## Abstract

A deep study on the effects of absolute pressure, peak temperature, gas residence time and gas atmosphere on the pyrolysis behaviour of wheat straw pellets in a bench-scale fixed-bed reactor has been carried out.

## Introduction

Biochar is widely considered as a renewable, promising solution to mitigate critical issues such as the global warming, the environmental pollution and the growing food demand [1]. It is a form of charred organic matter produced through the pyrolysis of biomass, deriving from several sources, such as forestry or agricultural residues, municipal solid waste and sewage sludge. Biochar can be used in a wide range of applications [2]: as fuel to produce heat and/or electricity, as soil amendment, in water and gas purification processes, among others. In this sense, depending on its final use, biochar must present specific properties, which will depend on the pyrolysis process conditions applied to produce it. Nevertheless, given the high number of variables affecting the pyrolysis process (e.g., pressure, peak temperature, heating rate, gas residence time) and the wide range of available biomass sources, several types of biochar with different properties should be expected. Hence, one of the main challenges nowadays is to optimize the process conditions of pyrolysis for a given biomass feedstock, in order to obtain biochar with the best properties for each application. Therefore, the specific aim of this study is to evaluate the effects of absolute pressure, peak temperature, gas residence time and gas atmosphere on the pyrolysis behavior of wheat straw pellets in a bench-scale fixed-bed reactor. Not only the effect of these parameters individually but also the possible effects derived from the interactions between them have been considered. For this purpose, an unreplicated 2-level factorial design has been adopted to objectively analyze the effect of these parameters on the response variables (i.e., yield of products, fixed-carbon yield, atomic H:C and O:C ratios). In addition to the statististical analysis of the above-mentioned response variables, the present study aims at analyzing the the real-time mass loss of the biomass along the pyrolysis process. This valuable information, together with the simultaneous analysis of the gas composition and the temperature profiles, represents a novel approach to assess the role played by the studied factors in the pyrolysis behavior.

## Experimental

### Materials and experimental conditions

Wheat straw pellets provided by University of Ghent have been selected as feedstock for the experiments of this work. The variable parameters were the absolute pressure (0.2–0.9 MPa), the peak temperature (400–550 °C), the gas residence time (100–200 s) and the gas atmosphere (pure $N_2$ or a binary mixture of $CO_2$ and $N_2$, 60:40 v/v). The soaking time (i.e., the time elapsed at the peak temperature) was kept at 1 h during all the experiments.

### Pyrolysis apparatus and procedures

The pyrolysis runs presented in this study were carried out in a cylindrical and vertical reactor made of stainless steel and electrically heated. The reactor was supported on a ceramic tube, which was placed on a weighing platform. More details regarding the configuration of the reactor are available in previous publications [3]. The composition of the gas fraction ($N_2$, $CO_2$, CO, $CH_4$, $C_2H_x$ and $H_2$) was determined using an Agilent micro-GC. Special attention was paid to the biochar yield and its properties related to the carbon sequestration potential. In this sense, the fixed-carbon content and atomic H:C and O:C ratios were considered as useful rough indicators of the long-term stability of biochar [4]. To get this information, all the produced biochars were characterized by proximate and elemental analyses.

# Results

Peak temperature confirmed to be the only variable parameter to markedly affect the biochar yield, as widely reported in literature [5–7]. In particular, the higher the peak temperature, the lower the biochar yield. This was mainly due to the thermal decomposition of cellulose and hemicelluloses [8], which typically occurs in a temperature range of 250–550 °C, depending on the feedstock nature. Peak temperature also played a key role on the final fixed-carbon content and atomic H:C and O:C ratios of the biochar. When it increased, its effect resulted positive on the fixed-carbon content, and, as expected, it was negative on the atomic H:C and O:C ratios, due to the thermal degradation of hydrogenated and oxygenated fuctional groups. It should be pointed out that the absolute pressure was another relevant parameter which affected the H:C and O:C ratios. An increase in pressure led to higher devolatilization rates and favoured the kinetics of degradation reactions [3]. Therefore, an increase in pressure resulted in a decrease in the H and O contents in the biochar. Furthermore, the pressure favoured the thermal cracking and steam reforming of intermediate volatile organic compounds, leading to a decrease in the cumulative yield of the total liquid (mainly water) at the expense of produced gas.

An increase in the gas residence time led to an increase in the biochar yield, favouring the secondary charring reactions, and partly improved the liquid yield, by enhancing the water production. On the other side, the presence of $CO_2$ in the reaction atmosphere showed no relevant effects neither on the distribution of product yields nor on the indicators of the long-term stability of biochar.

# Conclusions

The effects of absolute pressure, peak temperature, gas residence time and gas atmosphere on the pyrolysis behaviour of wheat straw pellets were deeply investigated. The peak temperature resulted to be the most significant variable parameter in terms of biochar yield and its potential stability. However, also the effect of pressure and gas residence time resulted non-negligible, proving that the best combination of them could provide remarkable improvements in the final properties of the produced biochar. Further investigations on the effects of $CO_2$ atmosphere on the biochar properties are needed, paying attention in terms of textural properties (i.e., in the development of microporous structures).


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