

Gaseous products formed during the pyrolysis of biomass in a drop tube furnace: experiments and modelling

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Biomass is one of the most abundant and used sources of renewable energy in the world with reduced impact on global warming. Biomass is becoming more relevant as an energy carrier due to its high diversity and availability. It includes plants, leftovers from agricultural materials and forestry processes, as well as organic industrial, animal and human wastes. Agricultural wastes, in particular, contain a high amount of organic constituents (cellulose, hemicellulose, lignin and minor amounts of other organics) and possess high energy content. Biomass can be upgraded through pyrolysis, which is a form of thermal treatment that decomposes organic materials into liquid, solid and gaseous forms in the absence of oxygen. All three-output fractions have potential as fuels for transports, power generation and combined heat and power. Most biomass upgrading processes are optimized to woody biomass; however, due to economic and environmental reasons, only a part of the available forest biomass can be used. In this context, in addition to forest biomass, it is critical to use also agricultural residues for energy purposes. The extreme variability of the biomass feedstock demands for an extensive investigation on the impact of its composition in their pyrolysis behaviour, especially in their gaseous products. The objective of this work is to investigate experimentally and numerically the gaseous products gaseous products formed during the pyrolysis of biomass in a drop tube furnace. Three biomass fuels (pine bark, wheat straw and rice husk) are used in this work, whose main characteristics are listed in Table 1.

Table 1. Characteristics of the biomass fuels studied.

Parameter	Pine bark	Wheat straw	Rice husk
<i>Proximate analysis</i> (wt.%, as received)			
Volatile matter	63.7	64.9	65.5
Fixed carbon	21.2	11.5	14.6
Ash	2.6	14.7	10.5
Moisture	2.6	14.7	10.5
<i>Ultimate analysis</i> (wt.%, dry-ash-free)			
C	52.6	51.6	52.1
H	7.4	6.8	7.2
N	1.0	0.6	0.6
S	0.0	0.0	0.0
O	39.0	41.0	40.1

The pyrolysis of the three biomass fuels was performed in the drop tube furnace (DTF) shown in Figure 1. The DTF is an electrically heated ceramic tube with an inner diameter of 38 mm and a length of 1.3 m. The furnace wall temperatures are continuously monitored by eight type-K thermocouples uniformly distributed along the combustion chamber. A water-cooled injector, placed at the top of the DTF, is used to feed the pulverized solid fuels and the nitrogen to the combustion chamber. A twin screw volumetric feeder transfers the solid fuels to an ejector system from which the particles are nitrogen-transported to the water-cooled in-

jector. In this study, measurements were carried out for all biomass fuels for DTF wall temperatures between 800 °C and 1100 °C. The solid fuels feed rate was 23 g/h and the total nitrogen flow rate was 4 L/min, ensuring ~2 second residence time.



Figure 1. Photograph of the drop tube furnace.

The major constituents of the gas products were measured by gas chromatography. After leaving the DTF the gaseous products passed through a quartz filter, followed by a gas washer, dried via silica gel, and then collected in a gas bag. The sampling time was 15 min and the yield of the gaseous products was calculated taking into account the nitrogen flow rate used. For each test, three independent measurements were performed.

The pyrolysis of the three biomass fuels is also studied numerically. To this end, a spherical, thermally thin biomass particle in an inert laminar flow is modeled. The particle mass, trajectory and temperature can be calculated at each time step from the solution of the following set of ordinary differential equations:

$$\frac{dm_p}{dt} = \frac{dm_{p,dry}}{dt} + \frac{dm_{p,pir}}{dt} \quad (1)$$

$$\frac{dx_p}{dt} = u_p \quad (2)$$

$$\frac{du_p}{dt} = \frac{u_p - u_g}{\tau} + \quad (3)$$

$$m_p c_{p,p} \frac{dT_p}{dt} = \theta h A_p (T_g - T_p) + \sigma \varepsilon_p A_p (T_w^4 - T_p^4) \quad (4)$$

Drying is modeled through equilibrium and pyrolysis rates and speciation are modeled using two approaches: the detailed bio-PoliMi mechanism and a simplified mechanism optimized using a genetic algorithm fitting procedure. The particle is affected by drag and gravity is assumed to follow the axial axis of the DTF. Only convection and radiation heat transfer are considered – the global heat of phase change during devolatilization is neglected due to lack of reliable data. The convection term is correct for high rates of mass transfer accounting for the Stefan flow.

The study presents and discusses the experimental and predicted gas yields from the pyrolysis of the three biomass fuels.