Multicriterial analysis of pyrolysis process of agricultural biomass waste, biodegradable waste, and RDF fuel

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The project involved the pyrolysis process of wastes. It was the response to the social need to reduce the amount of waste by producing added value products for fuel, chemical, and adsorbent applications.

The aim of the project was a multicriteria analysis of the pyrolysis process of agricultural biomass waste, biodegradable waste, and RDF fuel (Refused Derived Fuel). Pyrolysis is a thermal conversion process of a material, which consists of its decomposition in an inert atmosphere in the temperature range from approximately 300 to 900 °C. During pyrolysis, large and complex particles of organic material break down into smaller ones, giving products such as pyrolysis gas, liquid condensate (biooil), and solid phase (biochar). The physical and chemical properties of feedstock and process parameters such as heating rate, pressure, temperature, residence time, and the presence of a catalyst influence on yield product. Fast pyrolysis is an economical method for converting biomass waste into oil, which is characterised by a high energy density. However, oil obtained by fast pyrolysis has undesirable properties, such as low chemical stability and high acidity. Zeolites have been used effectively to decrease the oxygen content in oils. Zeolite ZSM-5 and Zeolite Y are commonly used to deoxygenate biomass pyrolysis vapours. The silica-alumina ratio (SAR) significantly affects the acidity and reactivity of a catalyst during biomass pyrolysis. Therefore, the effect of catalyst acidity (Zeolite Y: SAR = 26 and ZSM-5: SAR = 352) on biomass pyrolysis was investigated.
The proposed project contained innovative elements. The pyrolysis process was investigated in a unit specially designed by the authors which was applied in a special system to put the sample into the heated chamber. The proposed solution enables a very fast heating of the sample, from the ambient temperature to the process temperature.

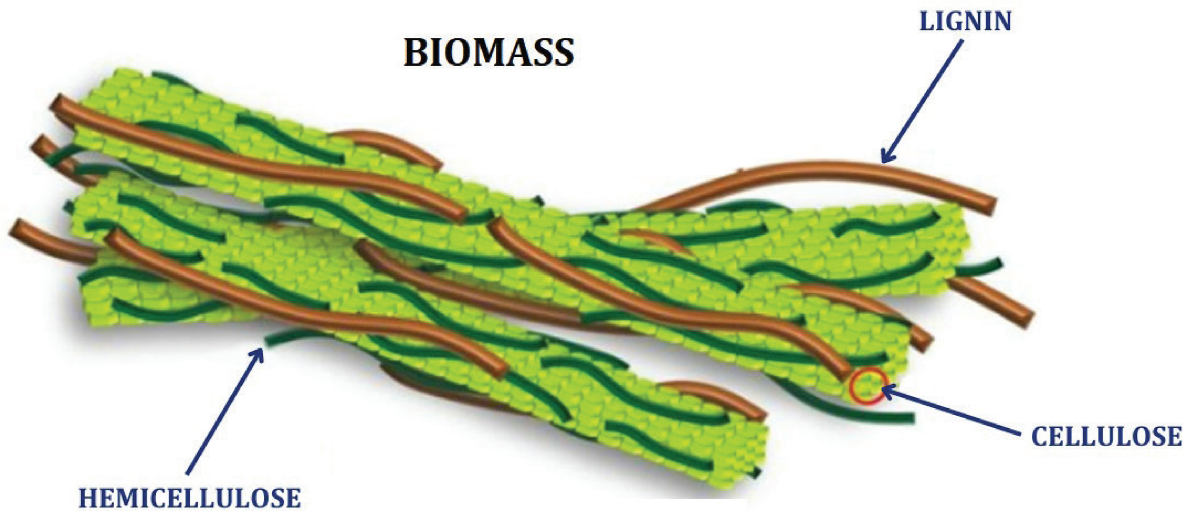

Figure 1. Scheme of biomass structure

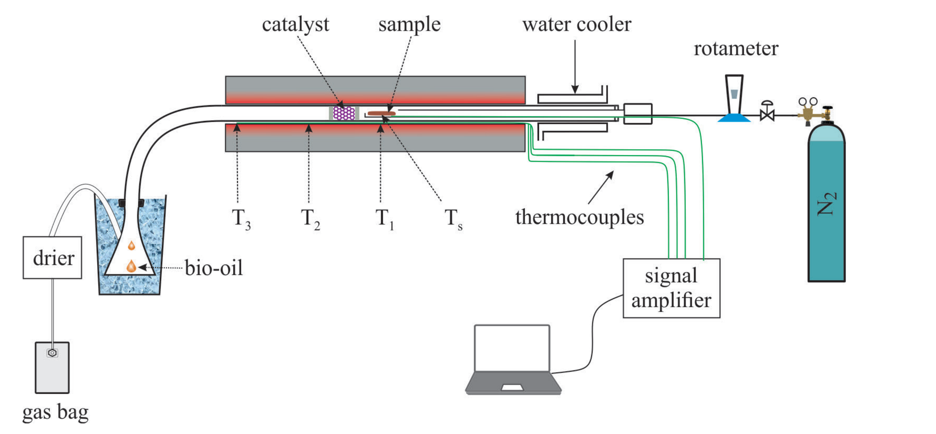

Figure 2. Experimental set-up for catalytic intermediate pyrolysis.

The biomass waste pyrolysis process was performed in the presence of zeolite catalysts under intermediate pyrolysis conditions for bio-oil production with low oxygen content. Furthermore, the obtained biochar was investigated because it has potential for further application as an adsorbent and catalyst for reducing gaseous pollutants during the combustion process. Then, the thermodynamic parameters (changes of enthalpy (ΔH), free Gibbs energy (ΔG), and entropy (ΔS)) of the pyrolysis process were calculated.
The following instrumental techniques were used for feedstocks and products of pyrolysis investigations: thermal analysis (TG/DSC/DTG), scanning electron microscopy (SEM) with EDS, X-ray X-ray fluorescence (XRF), Fourier-transform infrared spectroscopy (FTIR), gas chromatography (GC), pyrolysis gas chromatography mass spectrometry (Py-GC-MS) and mercury porosimetry.

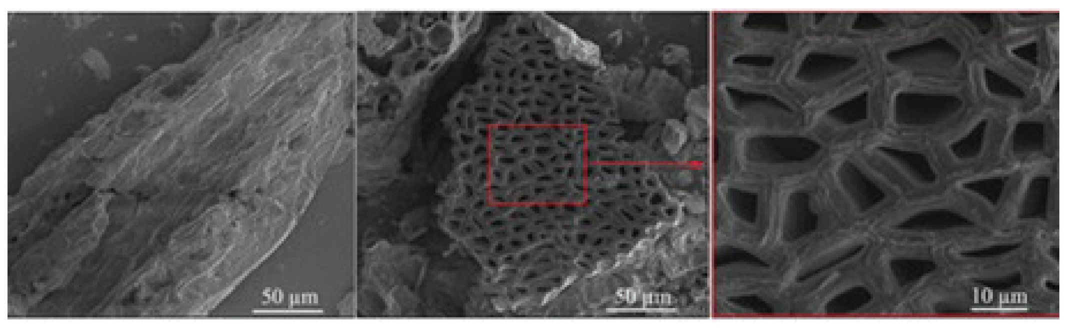

Figure 3. Scanning electron microscopy images of raw biomass and char

The kinetics for the pyrolysis of brewery spent grain (BSG) and medium-density fiber board (MDF) wastes was investigated in an argon atmosphere. The kinetic parameters, such as the average activation energy, the pre-exponential factor, and heterogeneous reaction model, according to the Arrhenius theory, were determined using three isoconversional methods developed by Friedman, Kissinger–Akahira–Sunose (KAS), and Flynn–Wall–Ozawa (FWO). The heterogeneous reaction model was determined with the use of the MasterPlot method.

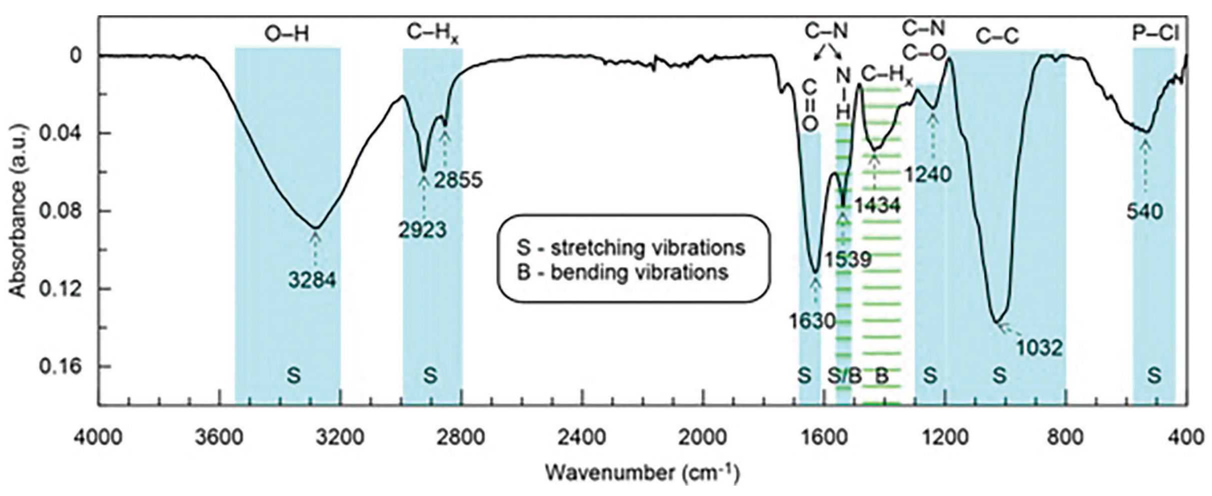

Figure 4. Fourier-transform infrared spectrum of rapeseed meal (biomass).

To enhance the knowledge for better understanding of biomass pyrolysis from experiments, the numerical studies were involved. The impact of the pyrolysis process parameters (heating rate, temperature, and vapour residence time) was investigated by CFD calculations in order to determine the yields of the product. The commercial software Ansys Fluent (with Euler – Euler multifluid flow model) was applied.

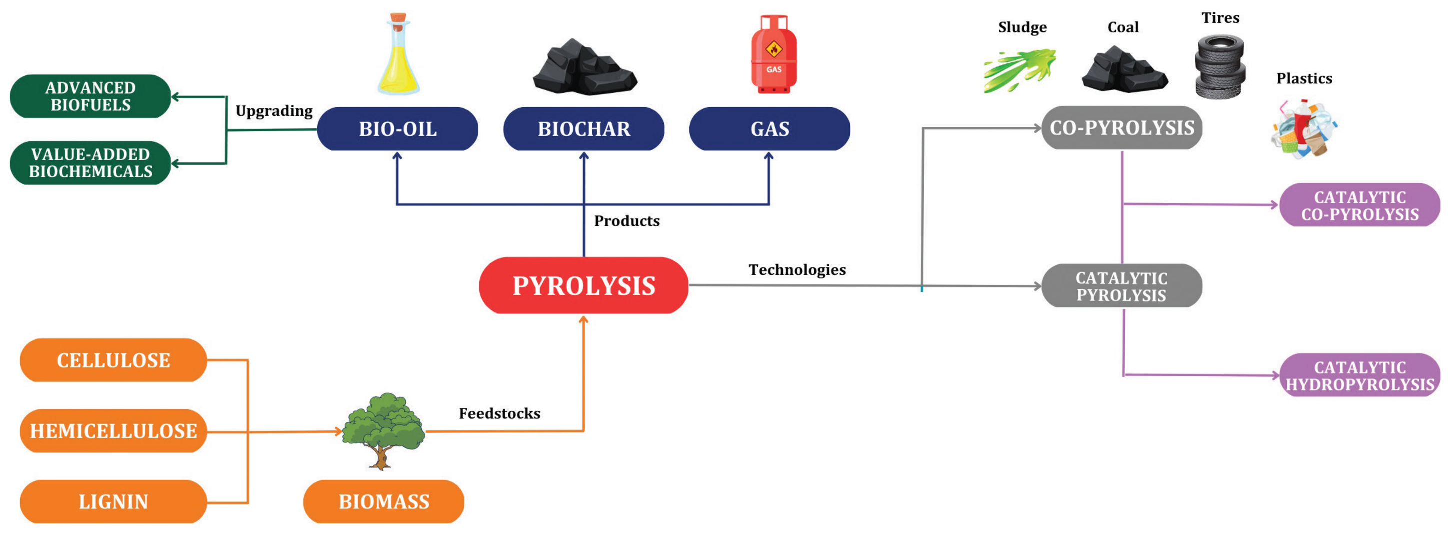

Figure 5. Scheme of pyrolysis process

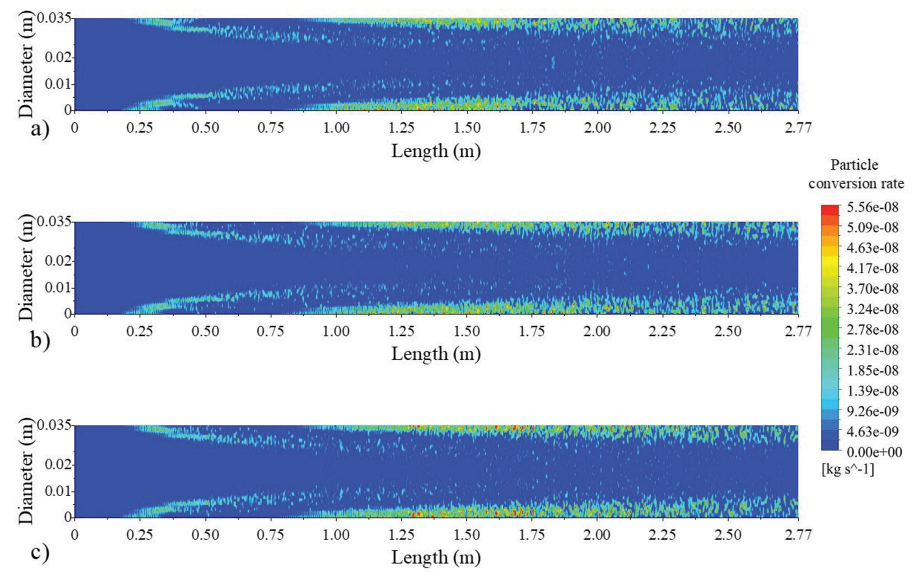

Figure 6. Particle conversion rate distribution of pine during pyrolysis under a) nitrogen atmosphere, b) 95% N_2/5% O_2, and c) 90% N_2/10% O_2.

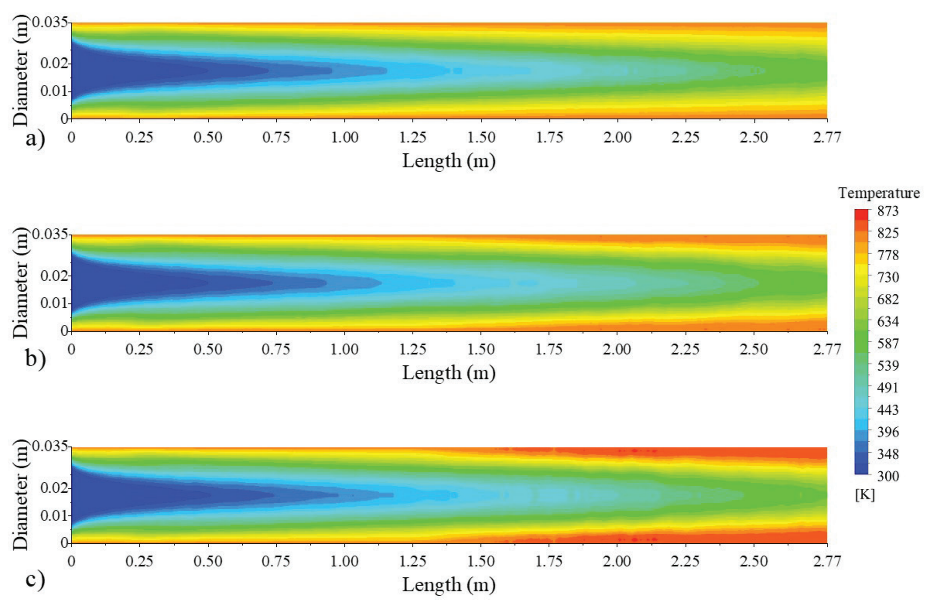

Figure 7. Temperature distribution of pine pyrolysis under a) nitrogen atmosphere, b) 95% N_2/5% O_2, and c) 90% N_2/10% O_2 at 7 s of computation.

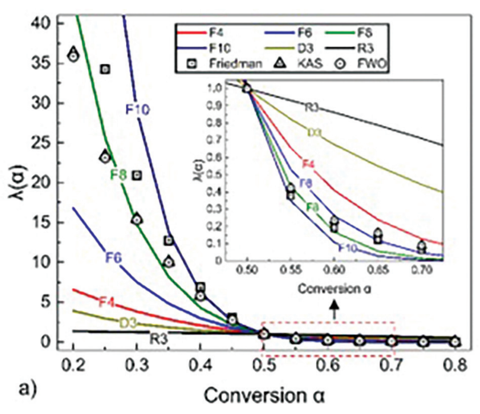

Figure 8. The generalized MasterPlot method for optimized reaction orders

References
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2. Wang F., Gao N., Magdziarz A., Quan C.: Co-pyrolysis of biomass and waste tires under high-pressure two-stage fixed bed reactor. **Bioresource Technology** 2022, 344, Part B, 126306. IF-9.642, TOP10, Q1.
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4. Jerzak W., Reinmöller M., Magdziarz A., Valorisation of biomass wastes via intermediate pyrolysis and estimation of the heat required for the pyrolysis process. **Clean Technologies and Environmental Policy** 2022, 24 (10), 3061–3075, IF–4.7, Q2.
5. Bieniek A., Jerzak W., Gajek M., Magdziarz A., Numerical investigations of biomass pyrolysis with partial oxidation in a drop tube reactor. **Journal of Cleaner Production** 2023, 401 (15), 136774, IF–11.072, TOP10, Q1.

Short-term research visits for establishing cooperation
1. University POLITEHNICA of Bucharest, Bucharest, Romania.
2. Aston University, Department of Chemical Engineering and Applied Chemistry, Birmingham, Great Britain.
3. University of Naples Federico II, Department of Chemical, Materials and Industrial Production Engineering, Naples, Italy.
4. University of Pannonia, Faculty of Engineering, Veszprém, Hungary.

Project application:
1. EU project, **HORIZON-MSCA-2021-SE-01-01** (MSCA Staff Exchanges 2021), "CUPOLA-Carbon-neutral pathways of recycling marine plastic waste", 2023-2026, Project ID:101086071. **AGH leader of consortium**, Aneta Magdziarz – principal investigator (PI) – financed.