Integrating Fenton Process with Plasma Technology for Enhanced Biogas Production from High-Lignocellulosic Biomass

Pranesh Kannappan Karthikeyan[1], Jovana Grbic[4], Felipe Iza[3], Himiyage Chaminda Hemaka Bandulasena[2*], and Tanja Radu[1*]

[1] School of Architecture, Building and Civil Engineering, Loughborough University, Leicestershire, LE11 3TU, United Kingdom.

[2] Department of Chemical Engineering, Loughborough University, Leicestershire, LE11 3TU, United Kingdom.

[3] Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Leicestershire, LE11 3TU, United Kingdom.

[4]Innovation Center of Faculty of Technology and Metallurgy, University of Belgrade, 11120, Belgrade, Serbia.

Keywords: Pretreatment, Microbubble Plasma Reactor, Biogas Production, Lignocellulosic Biomass, Renewable Energy, Sustainable Waste Management.

Corresponding author email: t.radu@lboro.ac.uk; h.c.h.bandulasena@lboro.ac.uk

Presenting author: p.kannappan-karthikeyan@lboro.ac.uk

The rising energy demands, and depleting reserve of fossil fuels have resulted in the need to explore sustainable and renewable energy alternatives (Ashokkumar et al. 2022). Lignocellulosic biomass, which is primarily composed of cellulose, hemicellulose, and lignin, is a promising renewable energy source that has the potential to meet global energy demands while mitigating climate change (Zeng et al. 2017). However, the complex and recalcitrant structure of lignocellulosic biomass, particularly its high lignin content, presents a major barrier to its efficient use for direct bioenergy production (Carrere et al. 2016). Anaerobic digestion (AD) is a well-established biological process that converts organic matter into biogas, a valuable renewable energy source in the absence of oxygen (Jwan J Abdullah and Chenyu Du 2020). However, the often high lignin content biomass hinders the utilization of biomethane in AD processes, necessitating pretreatment strategies to improve biodegradability and biomethane yield (Mohammad Rahmani et al. 2022). The pretreatment methods can be broadly classified into mechanical, chemical, thermal, biological, and combined approaches (Karthikeyan et al. 2024). The Fenton process, which is known for its strong oxidising properties, disrupts lignin's complex polymeric structure, increasing the accessibility of cellulose and hemicellulose to microbial digestion (Grbić et al. 2023). Concurrently, microbubble plasma technology, known for its high mass transfer efficiency and reactive species generation, can improve biomass degradation (Wright et al. 2020). This research integrates the Fenton process with plasma technology using a microbubble plasma reactor (Fig. 1) to address and the issue of low biodegradability and increase biomethane production. We applied the proposed pretreatment to maize and rice husks, as representatives of the most commonly grown crops with abundant post-harvest residues.

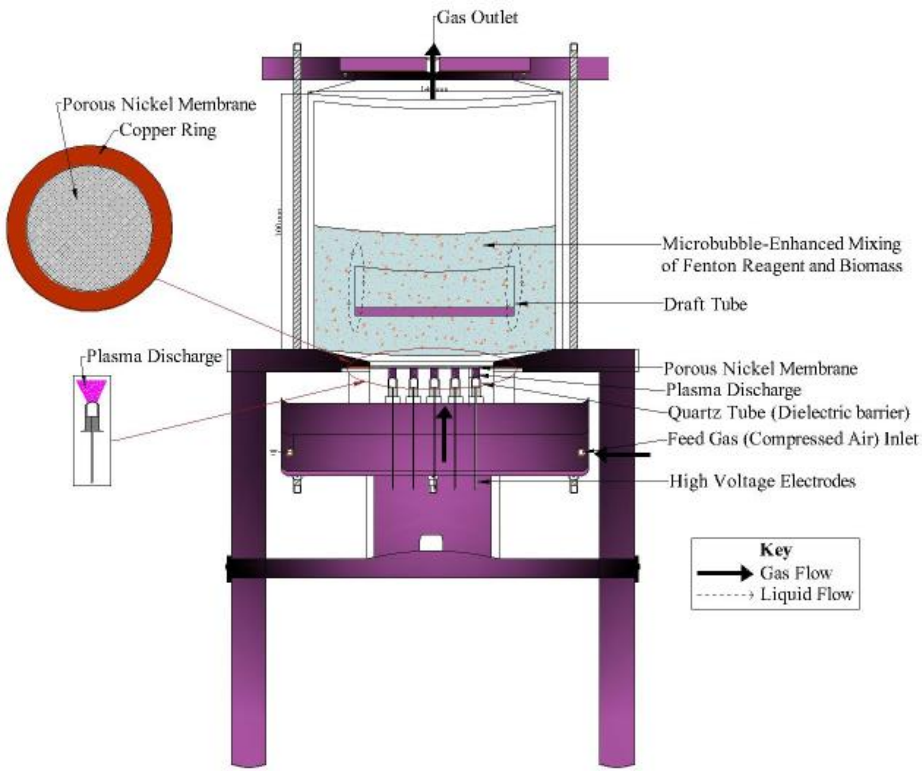

Fig. 1 A schematic diagram of the microbubble plasma reactor.

Combining the two pretreatment approaches results in a highly oxidised pretreatment environment setting, which aims to increase lignin breakdown, improve substrate biodegradability, increase substrate surface area, and maximise biomethane yield.

Plasma pretreatment with Fenton reagents was performed under various operating conditions, including different H_2O_2:Fe ratios (based on their mass) and pretreatment durations. The untreated and treated biomass was characterised using Attenuated total reflectance Fourier-transform infrared spectroscopy (ATR-FTIR) to monitor functional group changes, scanning electron microscopy (SEM) to examine surface morphology, and X-ray diffraction (XRD) to evaluate the crystalline structure, while biomethane production was assessed using the biomethane potential test (AMPTS II). Biogas production tests were carried out in a batch anaerobic digestion system to determine the biogas yield. The National Renewable Energy Laboratory protocol (Sluiter et al. 2008) was used to quantify Klason lignin content for pretreated and untreated biomass samples. Gas chromatography was used to determine the biogas composition. Simultaneously, lignin and hemicellulose fractions were recovered from the liquid phase after pretreatment, presenting opportunities for obtaining value-added products through biorefinery approaches.

Preliminary FTIR characterization results for whole maize plants and rice husks indicate that stand-alone microbubble plasma pretreatment for 1h and 3h pretreatment duration reduces the intensity of the peak associated with lignin and carbohydrate linkage, as shown in Fig. 2.

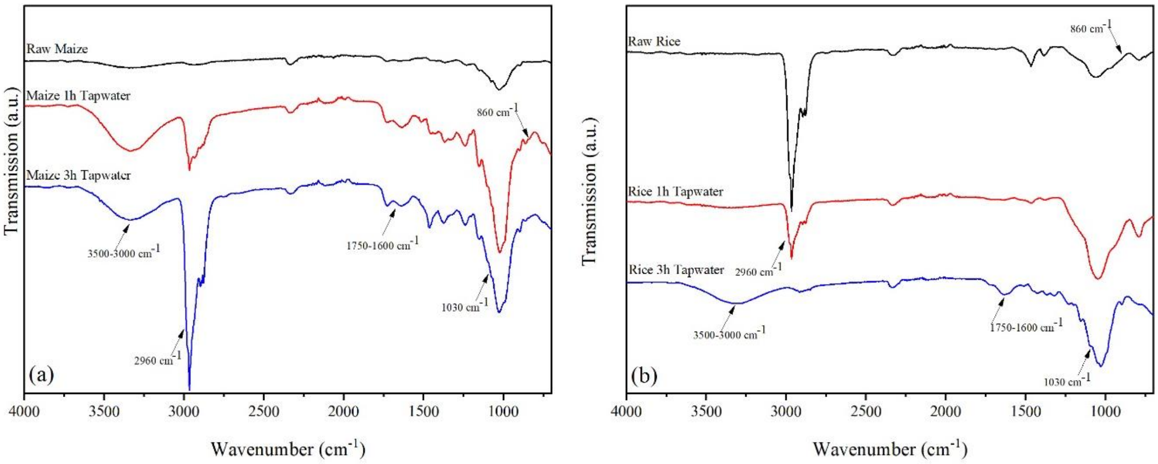

Fig. 2 FTIR Analysis for (a) Maize and (b) Rice Husk.

This study demonstrates the potential of integrating the Fenton process with microbubble plasma technology to improve biomethane production. It addresses the ongoing challenges of lignocellulosic biomass degradation, thereby facilitating the development of sustainable bioenergy solutions and waste management processes. Ultimately, this approach facilitates a critical shift towards a circular bioeconomy, thereby establishing a pathway to achieve the net zero target.

References:

Ashokkumar, V. et al. 2022. Recent advances in lignocellulosic biomass for biofuels and value-added bioproducts - A critical review. *Bioresource Technology* 344. doi: 10.1016/j.biortech.2021.126195.

Carrere, H., Antonopoulou, G., Affes, R., Passos, F., Battimelli, A., Lyberatos, G. and Ferrer, I. 2016. Review of feedstock pretreatment strategies for improved anaerobic digestion: From lab-scale research to full-scale application. *Bioresource Technology* 199, pp. 386–397. doi: 10.1016/J.BIORTECH.2015.09.007.

Grbić, J., Mladenović, D., Pavlović, S., Lazović, S., Mojović, L. and Djukić-Vuković, A. 2023. Advanced oxidation processes in the treatment of corn stalks. *Sustainable Chemistry and Pharmacy* 32. doi: 10.1016/j.scp.2022.100962.

Jwan J Abdullah, G.A.T. and and Chenyu Du. 2020. Anaerobic Digestion of Food Processing and Municipal Solid Waste (MSW). *Journal of Environmental Science, Computer Science And Engineering & Technology* 9(1). doi: 10.24214/jecet.a.9.1.03055.

Karthikeyan, P.K., Bandulasena, H.C.H. and Radu, T. 2024. A comparative analysis of pre-treatment technologies for enhanced biogas production from anaerobic digestion of lignocellulosic waste. *Industrial Crops and Products* 215, p. 118591. Available at: https://linkinghub.elsevier.com/retrieve/pii/S0926669024005685 [Accessed: 29 April 2024].

Mohammad Rahmani, A., Gahlot, P., Moustakas, K., Kazmi, A.A., Shekhar Prasad Ojha, C. and Tyagi, V.K. 2022. Pretreatment methods to enhance solubilization and anaerobic biodegradability of lignocellulosic biomass (wheat straw): Progress and challenges. *Fuel* 319. doi: 10.1016/j.fuel.2022.123726.

Sluiter, A., Hames, B., Ruiz, R., Scarlata, C., Sluiter, J., Templeton, D. and Crocker, D. 2008. *Determination of Structural Carbohydrates and Lignin in Biomass: Laboratory Analytical Procedure (LAP) (Revised July 2011)*. Available at: http://www.nrel.gov/biomass/analytical_procedures.html.

Wright, A. et al. 2020. Plasma-assisted pre-treatment of lignocellulosic biomass for anaerobic digestion. *Food and Bioproducts Processing* 124, pp. 287–295. doi: 10.1016/j.fbp.2020.09.005.

Zeng, Y., Himmel, M.E. and Ding, S.Y. 2017. Visualizing chemical functionality in plant cell walls Mike Himmel. *Biotechnology for Biofuels* 10(1). doi: 10.1186/s13068-017-0953-3.