Renewable Energy from Wastes: Enhanced Biogas Generation from High Lignocellulosic Biomass through Plasma-Assisted Microbubble Pre-Treatment

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The rapid depletion of fossil fuels and the significant environmental concerns associated with their use have led to the search for sustainable energy alternatives. The utilisation of biomass for energy production has received significant attention recently as a strategy to reduce carbon emissions and achieve the objectives of renewable energy and net-zero targets (Fox 2023). Biogas, an environmentally friendly and sustainable energy source, can be produced from organic matter using anaerobic digestion (Lohri et al. 2016). However, the high amount of lignin content (as shown in Table 1) present in lignocellulosic biomass, which is a significant component of plant cell walls, poses a hindrance to the production of biogas (Mohammad Rahmani et al. 2022). Conventional pre-treatment techniques, such as acid hydrolysis, require a significant amount of energy, involve the use of chemicals, and produce hazardous waste products. A novel alternative is the microbubble-enhanced dielectric barrier discharge plasma (MBDP) reactor, which utilises microbubbles to distribute highly reactive species produced in situ. This system improves enzymatic hydrolysis and biogas production while simultaneously minimising the generation of hazardous byproducts (Wright et al. 2020).

Table 1 Lignocellusic composition of mostly cultivated agricultural residues.

Crop	Lignin Content (%)	Cellulose Content (%)	Hemicellulose Content (%)	References
Wheat straw	11-26	32-45	20-45	(Del Río et al. 2013; Zhang et al. 2022)
Maize straw	12-19	41-37	22-31	(Yang et al. 2016; Mensah et al. 2021)
Rice straw	10-30	30-50	10-35	(Chen et al. 2020; Chen et al. 2021)

To enhance biogas production from high-lignocellulosic biomass (wheat straw, maize straw, and rice husk), this study examines the effectiveness of MBDP pretreatment by optimising the following operational parameters: treatment duration (1 and 3 hours) and pH (3 and 9). Attenuated total reflection-Fourier transform infrared spectroscopy (ATR-FTIR), thermogravimetric analysis (TGA), elemental analyser, scanning electron microscopy (SEM), and X-ray diffraction (XRD) are utilised to characterise the treated biomass and study changes in structure and composition of the pretreated material. Following MBDP treatment, ATR-FTIR and TGA analysis reveal a reduction in lignin content and an increase in cellulose accessibility. The disruption of biomass morphology is revealed by SEM images, and a reduction in cellulose crystallinity is determined by XRD analysis. Once pretreated, the feedstock is analysed using the biochemical methane potential (BMP) kit, to estimate the effect of pretreatment by determining differences in biomethane yield for untreated and pretreated samples. The results of BMP tests indicate that the biogas production from the MBDP-treated biomass is significantly higher than that of the untreated sample. We also report on the quality of biogas obtained following MDBP pretreatment. Furthermore, the experimentally obtained BMP biomethane yields are compared with the theoretical biomethane recovery calculated using the Buswell equation.

The results of this study provide support for the notion that MBDP pretreatment can significantly increase the production of biogas from biomass with high lignin content, all while avoiding the use of harsh chemicals and the generation of hazardous byproducts. Increased cellulose accessibility resulting from lignin degradation and reduced crystallinity are elements that promote enhanced enzymatic hydrolysis and biogas generation. Utilising MBDP for the pretreatment of high-lignocellulosic biomass is a sustainable and environmentally friendly approach, making it a promising technology for the production of renewable biogas from agricultural residues.

Finally, we provide an overview of obstacles and drivers towards adopting the MBDP technology on the industrial scale, by performing a basic comparison of the feasibility, and sustainability of the environmental impact across the range of pretreatment options.

References:

Chen, C. et al. 2020. Profiling of chemical and structural composition of lignocellulosic biomasses in tetraploid rice straw. *Polymers* 12(2). doi: 10.3390/polym12020340.

Chen, C., Deng, X., Kong, W., Qaseem, M.F., Zhao, S., Li, Y. and Wu, A.M. 2021. Rice Straws With Different Cell Wall Components Differ on Abilities of Saccharification. *Frontiers in Bioengineering and Biotechnology* 8. doi: 10.3389/fbioe.2020.624314.

Fox, A. 2023. *Biomass Strategy 2023*. Available at: www.gov.uk/official-documents.

Lohri, C.R., Rajabu, H.M., Sweeney, D.J. and Zurbrügg, C. 2016. Char fuel production in developing countries – A review of urban biowaste carbonization. *Renewable and Sustainable Energy Reviews* 59, pp. 1514–1530. doi: 10.1016/J.RSER.2016.01.088.

Mensah, M.B., Jumpah, H., Boadi, N.O. and Awudza, J.A.M. 2021. Assessment of quantities and composition of corn stover in Ghana and their conversion into bioethanol. *Scientific African* 12, p. e00731. doi: 10.1016/J.SCIAF.2021.E00731.

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.

Del Río, J.C., Rencoret, J., Prinsen, P., Martínez, Á.T., Gutiérrez, A. and Ralph, J. 2013. *Structural characterization of wheat straw lignin. Evidence for a novel monomer in grasses*.

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.

Yang, S., Zhang, Y., Yue, W., Wang, W., Wang, Y.Y., Yuan, T.Q. and Sun, R.C. 2016. Valorization of lignin and cellulose in acid-steam-exploded corn stover by a moderate alkaline ethanol post-treatment based on an integrated biorefinery concept. *Biotechnology for Biofuels* 9(1). doi: 10.1186/s13068-016-0656-1.

Zhang, L., Larsson, A., Moldin, A. and Edlund, U. 2022. Comparison of lignin distribution, structure, and morphology in wheat straw and wood. *Industrial Crops and Products* 187, p. 115432. doi: 10.1016/J.INDCROP.2022.115432.